Volume XXV January, 1928 Number 1

SOIL SCIENCE

FIRST INTERNATIONAL CONGRESS OF SOIL SCIENCE

A SUMMARY OF THE SCIENTIFIC CONTRIBUTIONS

PUBLISHED MONTHLY
THE WILLIAMS & WILKINS COMPANY
MT. ROYAL AND GUILFORD AVENUES
BALTIMORE, MARYLAND, U. S. A.

Made in United States of America

SOIL SCIENCE

FOUNDED BY
RUTGERS COLLEGE
NEW BRUNSWICK, N. J.

Entered as second-class matter May 12, 1919, at the post office at Baltimore, Maryland, under the act of March 3, 1879

SOIL SCIENCE

VOLUME XXV

JANUARY - JUNE, 1928

RUTGERS UNIVERSITY
NEW BRUNSWICK, NEW JERSEY
U. S. A.

PUBLISHED BY
THE WILLIAMS & WILKINS COMPANY
BALTIMORE, MARYLAND

10695

CONTENTS

ILLUSTRATIONS

PLATES

Professor K. D. Glinka

Organization and Program

First Commission, Soil Mechanics and Physics

Second Commission, Soil Chemistry

Third Commission, Soil Biology and Biochemistry

Subcommission II, Classification, Nomenclature, and Mapping of Soils in the United States

General Exhibits

A Study of the Protozoa of Some American Soils

The Volume Weight of Soils as a Physical Characteristic of the Soil Profile

Actinomyces Acidophilus N. Sp.—A Group of Acidophilus Actinomycetes Isolated from the Soil

A New Soil Sampler

A Laboratory Apparatus for the Measurement of Carbon Dioxide Evolved from Soils

The Influence of Heavy Applications of Dry Organic Matter on Crop Yields and on the Nitrate Content of the Soil

CALCIUM AS A FACTOR IN SOYBEAN INOCULATION

THE RATE OF AVAILABILITY OF VARIOUS FORMS OF SULFUR FERTILIZERS

A SIMPLE SPEED CONTROLLER, ESPECIALLY ADAPTED TO THE MOISTURE-EQUIVALENT CENTRIFUGE

TEXT FIGURES

THE TRANSCONTINENTAL EXCURSION

PHOSPHATE IN THE SOIL SOLUTION AS AFFECTED BY REACTION AND CATION CONCENTRATIONS

THE EFFECT OF DEHYDRATION OF SOILS UPON THEIR COLLOID CONSTITUENTS

Soil Temperatures in Saskatchewan

The Effect of Dehydration of Soils upon Their Colloid Constituents: II

A Laboratory Apparatus for the Measurement of Carbon Dioxide Evolved from Soils

The Effect of Growing Plants on Solubility of Soil Nutrients

Calcium as a Factor in Soybean Inoculation

The Relation of the Concentration of Calcium Ion Required by Alfalfa to the Amount Present in Soil Solution

Aqueous Vapor Pressure of Soils: III. Soil Structure as Influenced by Mechanical Treatments and Soluble Salts

Replaceable Bases and the Dispersion of Soil in Mechanical Analysis

A SIMPLE SPEED CONTROLLER, ESPECIALLY ADAPTED TO THE MOISTURE-EQUIVALENT CENTRIFUGE

AQUEOUS VAPOR PRESSURE OF SOILS: IV. INFLUENCE OF REPLACEABLE BASES

FIRST
INTERNATIONAL CONGRESS
OF
SOIL SCIENCE

A SUMMARY

OF THE

SCIENTIFIC CONTRIBUTIONS

HELD AT

WASHINGTON, D. C.

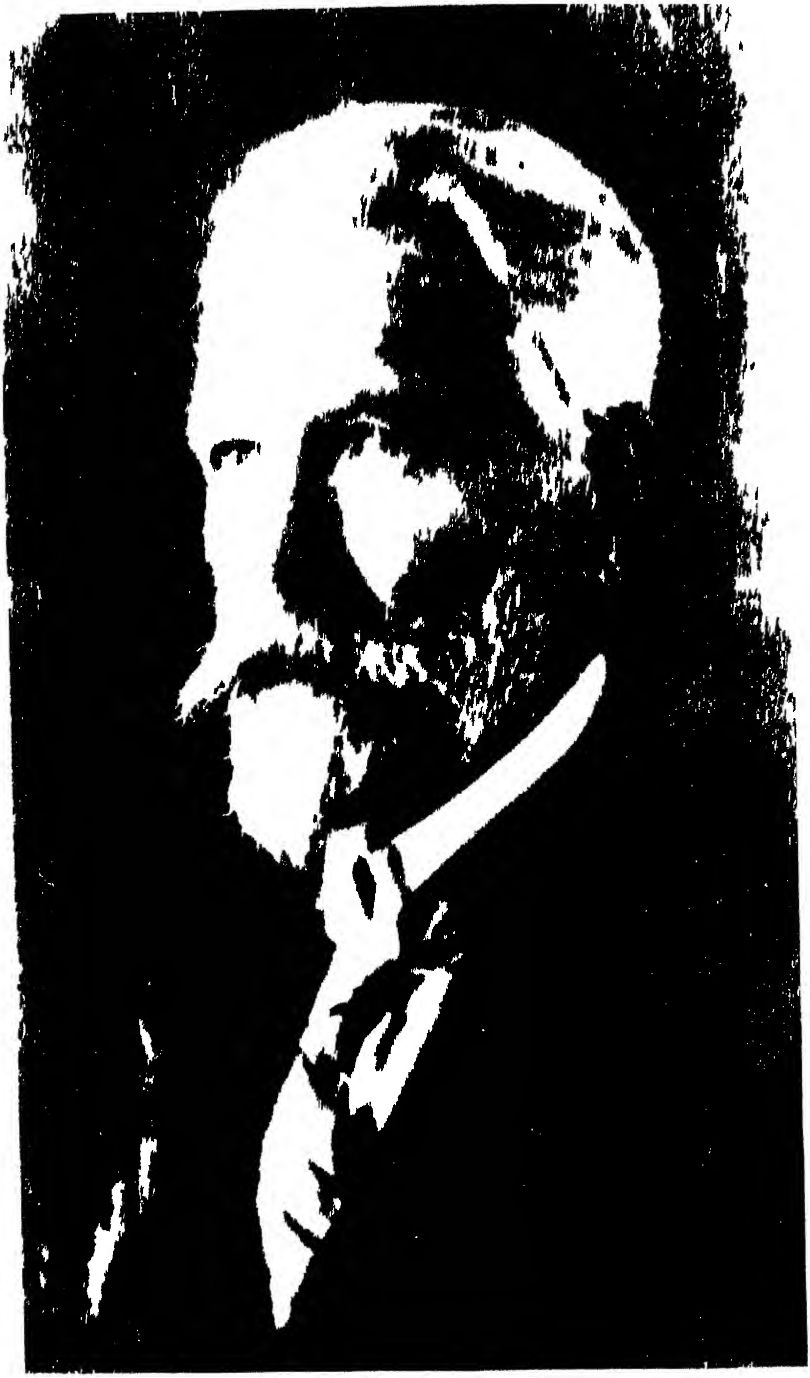
June 13–22

1927

To the memory of

PROFESSOR K. D. GLINKA

President-elect of the Second Soil Science Congress,
investigator and teacher, this number of
Soil Science is dedicated



PROF. K. D. GLINKA, PRESIDENT-ELECT OF THE INTERNATIONAL SOCIETY OF SOIL SCIENCE

PROFESSOR K. D. GLINKA

SELMAN A. WAKSMAN

At the time when this special issue of SOIL SCIENCE was ready for the press, news came of the death of Professor K. D. Glinka, the newly elected President of the International Society of Soil Science and of the Second Congress of the Society, which will take place in Russia in 1930.

In the death of Professor Glinka soil science and the International Society in particular have suffered a severe loss. An indefatiguable investigator, a brilliant teacher, one of the foremost pupils of the famous School of Dokuchaiev, the "father of soil science in Russia," Professor Glinka devoted his entire life to the study of soils, considered as a natural science. His constant dream during the last few years was to visit America and to determine to what extent the classification of soils developed by the Russian scientists holds true for the soils of this continent. The trip across the ocean and especially the transcontinental excursion following the Congress in Washington proved too great an exertion for his health. He became severly ill immediately upon his return to his home and died within a period of less than three months (November 2, 1927). Thus his very death was a result of over-exertion in connection with the subject to which he had devoted his whole life.

Born in 1867 in Smolensk, of an aristocratic family, Glinka studied at the Universities of St. Petersburg and Moscow, under the famous Dokuchaiev. Upon graduation from the university he was appointed lecturer at the Novo-Alexandria Institute, where he spent 18 years and where he did his most fruitful work. After he had earned a fully deserved pension he transferred his activities to St. Petersburg where he devoted himself to teaching pedology at the University and at the Higher Institute for Women. He took also an active part in the organization of the Dokuchaiev Soil Commission which has since gathered considerable information on the soils of Russia and adjacent countries. Professor Glinka himself carried out (during 1909-1913) a number of soil surveys in European Russia and in Siberia, in connection with land improvement and colonization.

In 1913, Professor Glinka was asked by the Russian Government to undertake the organization of a new Agricultural Institute in Voronezsh. He planned to spend a maximum of four years in the organization of the new Institute, expecting to see the graduation of the first class of students. The Institute was organized within two years, but the war prevented its completion and even the full equipment of the laboratories. The four-year period was prolonged to nine years.

During 1918–1919, when civil war swept throughout southern Russia, Professor Glinka found himself and his family carried back and forth between

the fighting armies. This whole period left a terrible impression upon him and resulted in a complete breakdown in health. The civil war period of 1918-1919 was followed by the hunger period of 1919 1920 and by the numerous epidemics accompanying starvation. It was only in 1921 when conditions became somewhat normal that work could be resumed again.

In 1922, Professor Glinka attended the Pedological Congress in Petrograd. There existed at that time in Petrograd three higher institutions for agricultural education, one of which was for women, one for young people who did not have a proper secondary training, and the regular department of agronomy of the university During the Congress, Professor Glinka was invited by the Russian Commissariat of Education to undertake the combination of the three institutes into one. He carried out this combination very successfully and was then elected as the first Rector of the Institute of Agriculture in Leningrad. He occupied this position during the last years of his life. He was at the same time a member of the Institute of Experimental Agronomy where he had charge of research investigations on soils.

As a final triumph of his activities, Professor Glinka was elected as a member of the Russian Academy of Sciences, the first soil scientist to be given this high honor. Russian soil scientists could now feel that they had attained a goal for which they had long been fighting, namely, the recognition of soil science as a natural science on an equal basis with the other sciences.

Among the other outstanding contributions of Professor Glinka to soil science are the several books which were used throughout the world as texts of soil science and which have made his name justly famous. Some of these are: *Types of Soil Formation, Classification and Geographic Distribution* (1913); *Soil Science* (1915); and *Soils of Russia and Adjacent Countries* (1923).

Professor Glinka took an active part in the first conferences on soil science and in the organization of the International Society in 1924 in Rome. It was due largely to his efforts that Russia was selected as the place for the next Congress, of which he was elected President.

Professor Glinka's name will occupy a prominent place in the roll of men who have devoted their lives to making the investigation of soils an exact science.

HISTORY OF THE ORGANIZATION OF THE INTERNATIONAL SOCIETY OF SOIL SCIENCE

The first attempt to bring together the various workers in the field of soil science was made in Budapest in 1909, when an agrogeological conference was called together at the invitation of the Royal Hungarian Institute. The conference lasted from April 14 to 24 and was attended by about 100 soil scientists, several countries (Germany, Russia, Rumania, Italy, Hungary, Austria, Belgium, and Norway) being also officially represented. The conference limited itself to general discussions of the origin of the soil and of the diversity of soil types. Suggestions were then made to adopt a uniform system of soil classification and uniform methods of laboratory investigations.

The Second International Agrogeological Conference took place in Stockholm in 1910. In addition to a number of countries represented by official delegations, 170 soil workers participated. The work of the conference was distributed among six sections dealing respectively with the mechanical analysis of soils, soil colloids, preparation of soil extracts for chemical anlyses, soil cartography, classification, and nomenclature of different soil types and soil conditions in various countries. Three international commissions were then organized which were supposed to investigate the various phases of the science and report at the following conference which was expected to take place three years later in St. Petersburg.

The outbreak of the war prevented the Third Conference from taking place and an interval of ten years elapsed before another attempt could be made to bring together again the soil workers from various countries. To this end D. J. Hissink of Holland submitted in September, 1921, a request to F. Schucht in Berlin and to J. Kopecky in Prague, which resulted in a circular letter being sent out in November, inviting soil scientists to assemble in Prague for a preliminary meeting, to arrange for calling the Third International Conference of Pedology. The adherents to the Pedological Conference that gathered in Prague in September, 1922, were so numerous (about 50 people), however, and were from so many different nationalities that this reunion was transformed, without any further formality, into the Third International Conference. The conference considered a number of questions pertaining to soils and completed the organization begun at Stockholm of the various international commissions of the International Committee of Pedology. The following five commissions were thus organized: I. Mechanical and physical soil analysis, with a subcommission on land cultivation; II. Chemical analysis of soil; III. Bacteriological analysis of soil; IV. Soil nomenclature; V. Soil cartography.

The International Pedological Committee then called the Fourth International Pedological Conference in Rome, Italy, in May, 1924. The necessary preparations for this conference were made in a preliminary meeting held June 7 to 10, 1923, in Zurich, Switzerland. Preliminary plans for the organization of the International Association of Soil Science were made at this meeting. The meetings of the executive committee of the Fourth Conference took place in Rome on May 10, 1924, where details of the program were discussed. The conference itself lasted from May 12 to May 19 and was accompanied by a number of receptions and excursions. The number of adherents to the conference was 463, representing 39 countries, although the actual number of participants was considerably less. The conference was divided into 6 plenary sessions, in addition to the opening session, and 15 sectional sessions.

In all, 280 communications were presented at the conference, divided among the various commissions. These communications and abstracts in three languages were later (1926) published in three volumes as *Actes de la IVème Conférence Internationale de Pedologie.* In addition to the previous five commissions, a sixth commission—Plant physiology and its relation to soil science - was organized.

The organization of the International Society of Soil Science was among the outstanding accomplishments of the Fourth Conference, J. G. Lipman was elected as the first president of the society. The United States was then selected as the first meeting place. The conference at Rome placed istelf on record as recommending more uniform methods of soil analysis, a definite nomenclature for soil classification, preparation of an international agrogeological map of Europe at 1/500,000 and 1/2,500,000, organization of soil investigations in countries where such investigations are not carried out, and introduction of the study of soils into programs of intermediary and higher schools.

For the preparation of the congress to be neld in Washington, the president of the society organized an American committee consisting of representatives of the U. S. Department of Agriculture and from all the United States and Canada. The committee decided to hold the Congress in Washington, beginning on June 13, 1927, to be followed by an excursion on a special train around the United States and Canada, to visit the representative soil types of North America.

Preliminary to the congress, a series of conferences were held by the various commissions, the first commission meeting at the Rothamsted Station in England, the second commission meeting in Groningen, Holland; the third in Berlin, Germany; the fourth in Düsseldorf, Germany; and the fifth in Hungary.

A summary of the contributions of the Soil Science Congress held in Washington is given herein, as reported by one of the members from each commission. The detailed Proceedings of the Congress will be published later.

ORGANIZATION AND PROGRAM

J. G. LIPMAN

President of the Society

(New Jersey Agricultural Experiment Station, U. S. A.)

The First International Congress of Soil Science held its meetings at the United States Chamber of Commerce, Washington, D. C., on June 13–22, 1927. The Congress was opened in person by President Coolidge. There was a large attendance of delegates and members from many countries. The names of the countries represented as well as the names of the delegates will be reported in the Proceedings of the Congress.

The program provided for general and sectional meetings, local excursions, various social functions, and extensive educational exhibits of soil maps, soil profiles, and material, apparatus, and equipment employed in carrying on soil investigations. There were between six and seven hundred people registered as participating more or less regularly in the meetings of the Congress. In addition, there were several hundred people who, as visitors, were present at one or more meetings or who spent some of their time in studying the different exhibits.

The delegates from other countries, as well as the American members and delegates, found the time to acquaint themselves with the City of Washington and its numerous attractions. Members of the Department of Agriculture and of other government departments and offices gave their whole-hearted interest and support toward making the sojourn of those attending the Congress both profitable and pleasant. Enthusiastic expressions of opinion were not wanting from members of the delegations from other countries. As individuals and as entire delegations they expressed their gratitude for having been given an opportunity to acquaint themselves with the vast agricultural resources of the United States and to establish personal relations with many colleagues in North America.

As we consider the First International Congress of Soil Science in retrospect, we conclude that much has been accomplished for soil science, for international good will and understanding, and for the more intensive development of the soil resources of many countries. There is no doubt that better coöperation has been provided for among soil workers, and better financial support for soil research at home and abroad. The contributions made by the Congress are not solely economic or scientific in their character, but have significant spiritual values. The soil workers of North American are grateful for having become better acquainted with their colleagues in other lands and for having laid the foundation for more effective professional coöperation.

FIG. 1. J. G. Lipman, Director of the New Jersey Agricultural Experiment Station, U. S. A., President of the Society.

FIG. 2. D. J. Hissink, Groningen Experiment Station, Holland, Acting President and Secretary of the Society.

FIG. 3. E. Ramann, one of the outstanding workers in Soil Science whose death, between the fourth conference in Rome and the Soil Congress at Washington, was a severe loss to soil science.

FIG. 4. O. Schreiner, U. S. Department of Agriculture, Chairman of the American Executive Committee (Courtesy National Fertilizer Assn., Copyright Harris & Ewing).

FIG. 5. A. G. McCall, U. S. Department of Agriculture, Executive Secretary of the Soil Science Congress (Copyright Underwood & Underwood).

Fig. 1 Sir John Russell, Director of the Rothamsted Experimental Station, England, honorary member of the Society
Fig. 2 P. Treitz, Hungary, honorary member of the Society
Fig. 3 H. Hesselman, Sweden, member of the General Committee, and prominent in the organization of the Forestry Sub-commission
Fig. 4 S. Winogradsky, Pasteur Institute, France, honorary member of the Society
Fig. 5 E. Schucht, Germany, Editor of the Society (Courtesy Better Crops Publishing Co)
Fig. 6 S. Miklaszewski, Poland, member of the General Committee

FIRST COMMISSION

Soil Mechanics and Physics

B. A. KEEN

Vice President

(Rothamsted Experimental Station, England)

The conclusion of the First International Congress of Soil Science affords a good opportunity for a critical survey of the present position of soil physics and a forecast of possible future activities. This branch of agricultural science has enjoyed a very definite revival in recent years. In the early days of agricultural science, about a century ago, physical problems received much study; indeed, Schubler's *Grundsatze der Agriculturchemie* published in 1838 in Leipsig was largely devoted to purely physical investigations, and the statement is to some extent true of Humphey Davy's *Elements of Agricultural Chemistry*, published some fifteen years earlier; Liebig's famous essay of 1840, and the experiments of Lawes and Gilbert, with their promise of a complex chemical theory of soil fertility, reduced the interest in soil physics to the vanishing point. A period of stagnation followed until Hilgard, Whitney, and King in America, and the contributors to Wollny's journal in Europe, set the subject once more on its feet. Wollny's journal, *Forschungen auf dem Gebiete der Agrikultur Physik* flourished during the two decades 1878–98, and is, so far as the present writer is aware, the only journal that has ever been devoted primarily to soil physics.

With the beginning of the present century a change of perspective took place. Up to this time the great majority of the investigations were empirical or *ad hoc* attempts to solve some practical problem of the behaviour of soil in the field in terms of elementary physical principles. The physical concept of the soil was correspondingly simple: it was regarded as a mixture of inert particles, something like a heap of sand, the soil moisture being distributed over the surface of the particles, and within the interstices, as a thin continuous film. The study, however, of the colloidal state of matter, to which scientists were giving much attention, had obvious applications to soil problems, and it soon became evident that the 'inert sand grain' hypothesis must be replaced or amended. The soil particle surfaces, especially those of the finest fractions, were not inert, but possessed the characteristic physical and physicochemical properties associated with colloidal material. A way was thus opened for an attack on fundamental soil properties from a new angle. Like all new ideas it suffered at first from over enthusiasm. 'Soil colloids' were endowed with marvelous and self-contradictory properties, and they could safely be blamed in every branch of soil science for all discrepancies in experimental data. This

enthusiasm has largely—but by no means entirely—died away, and been replaced by a clearer realization of the difficulties of both experiment and theory. In spite of much sound work we have not yet arrived at any really satisfactory understanding of the part played by colloidal forces in soil phenomena, nor perhaps would it be expected in so short a period of study, and with such complex and variable material; even with the comparatively simple colloidal systems used in pure science, many outstanding points of great difficulty still remain. However, the introduction into soil science of modern methods of physical chemistry, that has necessarily accompanied this sustained interest in colloidal properties, has broadened both the physical and chemical concepts of the soil, and in addition has provided excellent opportunities for effective cooperation and team-work.

In discussing the present position of soil physics, the Proceedings of the First Commission at the Washington Congress of the International Society of Soil Science will be taken as a general guide. As full abstracts of these papers were printed and circulated to all delegates it will not be necessary to give full references except to those papers from outside sources included in the present article.

It is convenient to begin with mechanical analysis. Up to a dozen years ago this was exclusively a routine operation, the soil particles being sorted into a few groups of specified limits of diameter. The results of such an analysis gave some degree of precision to the field observations of soil texture, and enabled investigators to fix empirical numerical standards for the descriptive terms—clays, silts, loams, sandy loams, etc.—used for the different soil classes. The conventional size limits for the different fractions, and the details of the experimental methods differed from one county to another and direct comparisons could not be made. Nevertheless, in spite of the crude nature of the process it did define in a measure, a fundamental and intrinsic property of the soil that was not directly altered either by cultivation or manurial treatment, and the advantage of an arithmetical classification instead of a purely descriptive one was evident in soil surveys, where many hundreds of samples had to be dealt with.

In 1915, Odén (12) showed that the concept of the mechanical composition of soil as a *continuous* function of particle size appeared capable of experimental realization. A mathematical examination of the conditions in a suspension of soil in water indicated that if the increase of weight with time on a pan suspended in the liquid could be measured, the results could be transformed into the desired particle size distribution curve. He devised an automatic balance that recorded the times at which successive definite increments of weight occured on the suspended pan, and thus he obtained the experimental time-weight curve.

Later, in conjunction with Fisher (7) he examined in more detail the mathematics of sedimentation with special reference to the various experimental methods that are theoretically possible; these methods are:

(*a*) Variation of density with depth at a constant time.
(*b*) Variation of density with time at a constant depth.
(*c*) Variation of hydrostatic pressure with depth at constant time.
(*d*) Variation of hydrostatic pressure with time at constant depth.

The difficulty of constructing apparatus to give the required degree of precision in the experimental data in the first three methods led naturally to a selection of the remaining one. Odén's method (weight of sediment) falls in this class, as does also that of Wiegner (17), in which the hydrostatic pressure at a given depth in the suspension is obtained from observations of the differences in level between the suspension and a balancing column of water connected to the suspension tube at the depth in question. One drawback in practice is the tedious mathematical analysis required to derive the second differential coefficient of the weight-time curve in the process of obtaining the size distribution curve. Graphical methods can be employed, but there is a loss of accuracy, and the better alternative is to make the experimental data as accurate as possible, and thus to reduce the magnification of experimental irregularities in the mathematical transformations. For this reason the original form of Odén's balance that depended on the intermittent addition of small steel balls to counterpoise the sedimentation pan, was improved at Rothamsted by the addition of electromagnetic control and a recording device giving a continuous chart of weight changes (5). In the course of this work Coutts and Crowther (6) employing fairly coarse suspensions observed discrepancies in their experimental results that were certainly not due to the apparatus itself. The trouble was traced to the shielding effect of the pan on the liquid immediately underneath, particles that would normally have passed into this region being of course held by the pan. The density of the suspension under the pan therefore became less than in the annular region around it, over which the pan did not extend, and interchange of liquid automatically followed, with consequent disturbances to the downward motion of the particles. A similar effect occurs in the Wiegner apparatus, because of the entry of water from the side tube into the suspension as the density of the latter decreases. In each case the disturbance is inevitable; it must persist throughout the experiment, and in Odén's method reaches serious proportions. The mathematical analysis of Fisher and Odén (7) applies, in fact, to only an ideal case quite unrealisable in practice, and in all probability, the attempt to extend it to include the effect in question, would present insuperable difficulties. Many experiments were made with different designs of pans and with guard rings, in an endeavour to reduce the error to manageable proportions, but without much success. Shaw (1, p. 5) has produced evidence to show that further discrepancies occur, especially with the finer particles, because of a motion toward the walls of the cylinder under the influence of electrical forces. Unless these inherent errors can be nullified— and the prospect of this does not appear very hopeful—it must be concluded regretfully that Odén's elegant experimental method fails to give an accurate particle-size distribution curve.

Meanwhile Crowther (1, p. 13)[1] has explored the experimental possibilities of method (*b*)—the rate of change of density at a given depth in the suspension Two points about five centimeters apart near the bottom of the sedimentation tube were connected through side tubes to the two arms of a sensitive manometer, and the difference in level of the manometric liquid (aniline of density 1.02) was taken as directly proportional to the density change in the suspension at the points midway between the two side arms. The arrangement has the great advantage of giving experimental values that are directly proportional to the summation percentage curve of the material. From these values the distribution curve is derived by a single differentation instead of the two that are needed in the methods of Odén and Wiegner. In its present form an accuracy of 1 to 2 per cent is obtainable; hence although the same error mentioned in connection with the Wiegner apparatus comes in the summation percentage curve has the same order of reliability as those constructed from results of the pipette method of mechanical analysis, which is hereafter discussed.

The pioneer work of Odén directed attention to the condition in a soil suspension and several investigators realized that the tedious pouring off of suspensions in the sedimentation method of mechanical analysis could be avoided by withdrawing a sample from the suspension at a fixed depth and time. The development of the technique, the now well-known "pipette" method, was achieved independently by Krauss (10) in Germany, Robinson (16) in Wales, and Jennings, Thomas and Gardner (8) in America—a rather remarkable example of simultaneous independent work. The experimental results, although expressed in concentrations, are in effect density determinations and correspond to isolated points on the summation percentage curve.[2] The percentage of particles comprised within each range of velocity of fall (or of particle diameter)— the limits being fixed by the times and depths of sampling —is obtained by successive subtraction in the series of experimental determinations. Thus, a mechanical analysis, expressed either as a summation percentage curve or as percentage of each soil fraction, is obtainable by a few pipette samplings from the one bulk soil suspension and the tedious pouring off of the clay fraction in the old beaker method, extending sometimes to several weeks, is avoided.

However, in the beaker method, incomplete initial dispersion merely lengthens the period of experiment, whereas in the pipette method it produces

[1] Also *Jour. Soc. Chem Ind.* 46 (1927) 105T–107T. The apparatus was demonstrated at the Rothamsted meeting of the First Commission in October, 1926.

[2] So, also, does Bouyoucos' determination with a hydrometer of the density of suspension after 15 minutes standing (1, Addenda, p. 17). The determination is essentially qualitative since an appreciable density difference must exist in the suspension between top and bottom of the long hydrometer bulb after so short a period as 15 minutes As the values appear to be related to those obtained in the Bureau of Soils method of estimating colloidal content by the heat of wetting, Bouyoucos suggests that the hydrometer method can be used as a rapid alternative.

positive errors in the results because of aggregates of smaller particles behaving as single large ones. It became essential, therefore, to examine more fully the experimental methods adopted to secure dispersion of the particles.

At this point it is necessary to digress somewhat, to discuss the different attitude of workers in various countries towards this question of dispersion of the soil particles. It has always been the practice in Great Britain and America to regard a mechanical analysis as a specification of the ultimate particle structure, whereas in Central Europe it is regarded more as an expression of the state of division that would be obtained under severe but not impossible weather conditions and cultivations. For this reason, the preliminary treatment in the laboratory is less drastic in the latter case: Boiling or agitation with water is employed, as compared with acid treatment to dissolve the cementing carbonates, followed by ammonia for deflocculation in the original British method (2). The relative merits of these two procedures are fully discussed in a report by a subcommittee of the Agricultural Education Association of Great Britain (3), in which is shown that much wider variations occur in the replicate results with the European method of dispersion. This effect, of course, is to be expected. The dispersive action is not sufficient even to break up the aggregates produced by a preliminary air-drying at ordinary temperature, a well-known effect on which further data are produced by Smolik (1, p. 38).

But although the British practice secures practically complete dispersion with ordinary soils, it appeared possible that soils containing considerable amounts of organic matter were incompletely disintegrated. Robinson was led to suspect this because of the relatively low percentage of clay in the mechanical analyses of certain Welsh soils of heavy texture. This was possible because of the smaller particles being held to one another and to larger particles by organic matter. When the soil was treated with weak hydrogen peroxide prior to the acid treatment, the humified organic matter was decomposed and considerably higher percentages of clay were obtained (15). After exhaustive trial, the peroxide-acid-ammonia dispersion treatment, together with the pipette method of sampling, has been adopted as the official British method of mechanical analysis[3] in place of the old beaker method (2). There are many soils for which the peroxide pretreatment is not absolutely necessary. Some heavy clay soils and subsoils can be dispersed by the simple addition of sodium carbonate solution (9); hydrochloric acid followed by caustic soda is also effective with many soils (1, p. 3). With soils known to contain much humus, and with unfamilar samples, the peroxide method should be employed.

The advances briefly sketched above have been closely followed by the International Society of Soil Science. Eventually at Rome in 1924, a full cooperative program was agreed to, the results of which were fully discussed at the First Commission meeting at Rothamsted in October, 1926. The con-

[3] *Agr. Prog.* (1926) 3: 106–110.

clusions[4] were printed and circulated before the Washington meeting where they were adopted with minor alterations. Two procedures were recognized: (*a*) for ultimate mechanical analysis (complete dispersion), (*b*) for technical and petrographical purposes. Method (*a*) is substantially the British official method, whereas (*b*), although admittedly empirical, is used extensively in Europe, for practice and advisory purposes. Results intended for international circulation will henceforth be given by method (*a*). Agreement was also reached on the relationship to be assumed between velocity of fall and size of particle. The correspondence assumed was a fall of 10 cm. in 8 hours at 20°C. for a diameter of 0.002 mm., other settling velocities to be calculated from this standard by Stoke's Law. The report also emphasized the advantage of graphic representation of the results on a summation percentage curve, using the logarithms of the settling velocity as abscissae.

The interest in mechanical analysis has extended to the apparatus employed in routine work and to the method of representing the results, and improvements in technique have followed. Corrections of setting velocities for temperature are now made more frequently. The calculations for this purpose are avoided with the nomograph suggested by Crowther (1, p. 18), the revised values being read off directly by placing a straight-edge across the chart in the appropriate position. As the logarithm of the settling velocity is used in summation percentage curves, a nomograph can also be employed, in which the correction of these values for temperature, and the corresponding heights and times of sedimentation can be read directly. Krauss (1, p. 12) showed that for forest soil conditions the ordinary range of particles dealt with in mechanical analysis was too restricted, differentiation of such soils occuring frequently in the proportion of gravel and even larger fractions. Hence there was a need for the graphic representation (using the logarithm of the diameter) to be extended beyond the upper size limit of the usual mechanical analysis. Albert (1, p. 9) described a specific instance from the sand dunes at Eberswalde, where the greater the proportion of particles of diameter above 0.2 cm., the less suitable were the conditions for growth. The ordinary elutriation method of mechanical analysis failed to show any differences, hence in conjunction with Köhn he devised an automatic flow apparatus, controlled by a constant speed centrifugal pump, that gave adequate separation of the particles in the region of this critical diameter (1, p. 10).

We may briefly summarize the present position of mechanical analysis as follows: The original promise of Odén's elegant method of obtaining a very accurate and detailed distribution curve has not been fulfilled, because of the inherent disturbances caused by the presence of the pan; the methods of Wiegner and Crowther are subject to exactly the same type of error, but it is of less relative importance, since these procedures do not profess to give results of the degree of detail contemplated in the Odén method. But although the

[4] Conclusions of First Commission. Rothamsted, 1926. Printed by "Robritkatiskana," Brno, Czechoslovakia, 1927.

fundamental research aspects of particle size have not progressed as much as has been hoped, the effect of this work in raising the accuracy of routine determinations of mechanical analysis has been very great. Not only have greatly improved methods been introduced and officially adopted, but complete unity has also been secured in the method to be adopted for results intended for international circulation. In view of the wide divergencies among the routine methods in different countries, and the natural unwillingness of workers to modify empirical details, the outcome of the First Commissions' activities may be regarded as highly satisfactory.

Nevertheless, the correlation of mechanical analysis results with field behaviour appears destined to remain indefinitely in the qualitative stage. The question of supplementing or replacing data of this kind by direct determinations of physical properties—preferably those of the 'single-value' type, giving one figure in place of the group of figures (or the summation curve) of a mechanical analysis has received much attention; it was specially considered by the First Commission at Washington, and has been adopted for the next cooperative investigation. The idea of single value determinations is not new. The wilting coefficient, moisture equivalent, and hygroscopic coefficient are well-known examples, and there are many others. Those in use at the Bureau of Soils were described by Davis and Adams (1, p. 29) and include besides the above, percolation, amount of colloid, pore space, penetration, and plastic range. The authors state that no single method serves adequately to distinguish a soil. We may ascribe this to two reasons: firstly, the complex nature of the material; and secondly, the empirical nature of many of the single-value determinations. The time is ripe for a thorough examination of these methods to ascertain what physical property—or more generally, combinations of properties—are really involved in each method.

The 'hygroscopic coefficient' is a case in point. Physically the conception of moist soil being in equilibrium with a saturated atmosphere is unsound; the vapor pressure—moisture content curve is asymptotic at full saturation (14) and Puri's measurements (13), made in the writer's laboratory with full precautions show that the soil continues to take up moisture almost indefinitely. Apart from this, the difficulties in maintaining a chamber at exactly the saturation vapor pressure are almost insuperable under the experimental conditions. This was brought out both in Puri's work, and in the later investigations of Linford (11) who showed that more water was taken up by the soil when kept in the dark than when exposed to light, an effect probably due to an increase in temperature of the soil by absorption or radiation.

It is clear that the values customarily determined and referred to as the "hygroscopic coefficient" refer to some indefinite point on the asymptotic portion of the vapor pressure curve, and the fact that reasonably reproducible values are obtained is evidence, not that an equilibrium value is being measured, but merely that the empirical experimental conditions are reasonably reproducible. If some measure of soil moisture content be desired under

laboratory conditions, it is much easier and simpler to select some definite vapor pressure below the saturation value, such as that given by [illegible] per cent (by volume) sulfuric acid. This strength is used in the Bureau of Soils as a standard empirical measure of the absorption of water vapor by colloidal clay. The influence on this method, of such factors as temperature, pressure, degree of aggregation, and time of exposure has been examined by Middleton (1, p. 30).

Another 'single value' determination, of which considerable use has been made, is the moisture equivalent. As orginally developed by Briggs and McLane (4) the centrifugal force was fixed at a value that removed the water from the larger interstices of a saturated soil. The amount of water remaining could be taken as a measure of the composite effect of both texture and structure in conferring a moderate degree of immobility on a portion of the soil moisture. The working details were of course empirical. Veihmeyer and Oserkowsky (1, p. 55) have recently made suggestions for improvement, based on an extended examination of the technique, with especial reference to the previous treatment of the soil and its condition at the time of the experiment.

The whole subject has been reopened by Keen and Coutts (1, p. 31). Some forty soils of different types were used and an attempt was made to assess the relative contribution of the organic matter and the mineral portion of the soil by repeating the 'single value' measurements on the soils after treatment with hydrogen peroxide. The two sets of data were examined by statistical methods, and some suggestive correlations have emerged. The moisture content when the plastic mass of soil is just becoming sticky—one of the 'single value' measurements—was highly correlated with the loss on ignition but not with the air-dry moisture figures. These latter were highly correlated with the amount of clay present in the soil. It would appear that the 'hygroscopic' water is held mainly in the minute capillaries in and among the clay particles, whereas the water needed to saturate the soil up to the sticky point is a function of the organic matter and the so-called "water of combination" of the clay. The organic matter plays an important part in this connection as shown by the appreciable and systematic decrease in the sticky point figures for the peroxide treated soils. The sticky point measurement is worthy of further study as a laboratory determination affording some guidance in the investigation of soil structure and tilth. Burr and Russell (1, p. 68) have examined the effect of organic matter in this direction, and describe suitable apparatus for measuring tilth properties.

It is obvious that such properties will exert an important and perhaps controlling influence on the field characteristics of a soil. They are affected both by season and by cultivation and manurial treatments, and have therefore direct bearing on the modern system of soil classification, and the art of arable agriculture; it is appropriate to consider them under each of these heads.

The modern system of soil classification based on profile examinations, was in the first instance very largely a visual classification. Now that these principles are generally accepted by soil scientists, the matter of introducing

quantitative physical and chemical determinations of the properties of the successive profiles is receiving attention Crowther (1, p. 26) describes some very simple and effective physical methods of studying soil structure that he used in an investigation of the profiles of heavy alkaline soils now being irrigated for cotton in the Sudan Gezira. These methods showed that the hard impermeable layer found at a depth of 70 to 100 cm , was not produced simply by closeness of packing, but was conditioned to a certain extent by some intrinsic property of the material. Gracie (1, p. 4) has carried out mechanical analyses of characteristic Scottish soil types, in which the influence of the parent rock on mechanical composition is still evident, in order to ascertain the present stage of development of these soils.

In connection with the mechanical analysis of soils for technical and petrographical purposes, the extensive work of Kopecky (1, p. 34) in Bohemia must be mentioned: numerous measurements of absolute water and air capacity, optimum moisture content, and permeability are being employed for the specification of the field behavior of soils in their relation to moisture. The type of investigation that is complementary to such measurements is the study of soil moisture contents under different systems of cultivation, and the relation between the values and the different kinds of soil structure produced by the implements. Novak and Simek (1, p. 39) have shown that in Czechoslovakia, implements of the cultivator type encourage the formation of a crust on the soil; the variations in moisture content, and the actual loss of water, were greater than in the case of the plots that were ploughed. In cases where numerous moisture determinations have to be made, the usual method of 24 hours drying at 100° to 105°C. becomes rather tedious. Bouyoucos (1, Addenda, p. 15) has examined the possiblity of a rapid determination by measuring the density of the alcohol-water mixture obtained when alcohol is thoroughly mixed with the moist soil. The main difficulty will no doubt be experienced in securing adequate disintegration of the lumps in heavy clay soils.

The subject of the movement of soil moisture is fundamental in soil physics. The factors concerned, such as vapor pressure, changes in viscosity and surface tension due to temperature fluctuations, capillary movements, etc., have been closely studied by numerous workers, and there is a general agreement that the operation of these forces is effective only over limited distances, and within a narrow range of moisture content. Lebedeff (1, p. 40) however, claims that the effects operate over large depths, and result in very appreciable accessions and losses of moisture from the soil in continental areas. It is exceedingly difficult to see, on the present evidence, how this can be admitted, but judgment must be reserved until the full experimental data and field observations are available Meanwhile, there is definite evidence from Keen's (1, p. 53) experiments that under conditions of severe drought, the ground water level is practically unaffected, even when it is less than 100 cm. from the soil surface, in a heavy loam soil; it may be concluded that in field conditions, upward movement of water by capillarity is slow and limited in range.

The demonstration, by profile examinations of the variation of soil properties with depth, has an important bearing on the physical behavior of soil in field conditions, for the factors briefly discussed above are not constant, but may vary in intensity from depth to depth. Recent work by Keen and Haines (1, p. 24) at Rothamsted on soil cultivation has shown that physical properties may also vary to a large degree in a lateral direction. The method consisted in measuring by a dynamometer the resistance of the soil to the passage of a cultivation implement. Marked differences were found, amounting in some cases to over 50 per cent, even within a limited area that to expert visual examination appeared uniform. The differences are not affected by season, and appear to persist indefinitely. On some of the experimental fields where each plot has received a given manurial and cultivation treatment, in some cases for more than eighty years, these variations in resistance can be traced across the plot boundaries without any change in value. These variations from point to point are the complex expression of corresponding changes in the inherent physical properties of the soil in a lateral direction. They emphasize the necessity of careful and full sampling of soil for laboratory investigations, since it is not possible to tell from field inspection whether the soil is really uniform. Much work remains to be done in relating the dynamometer measurements to physical properties of the soil, such as cohesion, plasticity, and colloidal characteristics. Meanwhile, the dynamometer technique has some important and immediate uses. It can be employed to obtain a rapid survey of the degree of heterogeneity of an area in connection with a soil survey, or for the selection of a uniform area for field experiments. It is also an essential preliminary in trials of implement draught, for it is impossible to make a fair comparison between two implements working in heterogeneous material unless the variations of the latter are known and allowed for. In the past the taking of dynamometer records was not an easy matter, because of the attention required by the instrument, particularly the recording portion. In damp weather the adjustment of the stylus to give a legible trace without tearing the paper required constant alteration.

Haines and Keen (1, p. 21) have evolved a new type of dynamometer that is free from this objection and is also suitable for use over any range of draught with the same percentage of accuracy. The recording portion is an adaptation of the well-known Stress Recorder manufactured by the Cambridge Instrument Company, London, England. The records are impressed on celluloid ribbon by a stylus, and are permanent, and unaffected by oil, water, or dirt. Two auxilliary styluses are provided, controlled electromagnetically; one gives a time scale for measuring speed of work, and the other, connected to a tapping-key, records in the morse code, any notes or position marks needed during the experiment. The instrument is very light, and the recording portion weighing about ten pounds, and the hydraulic link that is placed in the hitch, about the same amount. The instrument requires no attention and has given every satisfaction in a wide variety of conditions.

Albert (1, p. 35) has devised an ingenious apparatus for measuring the soil resistance in forests, where the above technique is obviously inapplicable. It consists of a pointed steel rod that is thrust downward into the soil. A graphic record of the change of resistance with depth is automatically obtained on a small drum carried in the upper portion of the apparatus. The instrument has been used to demonstrate changes in soil structure associated with different species of trees; its compactness, ease, and rapidity of operation should secure for it a wide sphere of usefulness in soil investigations.

Finally, it is of interest to note that the First Commission proceedings were almost completely devoid of papers dealing specifically and exclusively with soil colloids, a fact that emphasizes the comments in the introduction to this paper. We may anticipate, when the laboratory studies of the colloidal behavior of the finest soil particles have been carried a stage further, that serious attempts will be made to bridge the present gulf between the properties of weak suspensions and the behaviour of the soil in the field.

Meanwhile the reopening of the subject of single-value determinations and its selection as the next cooperative work of the First Commission may give an insight into the physical factors most concerned in the field behavior of soil. It will be wise not to be too optimistic over the immediate outcome of this cooperative work. An exact specification, in physical terms of the elusive group of properties known as "soil tilth" is, as yet, hardly in sight. However, we may hope by a thorough test of suggested methods to replace empirical details (or even methods) by absolute determinations, and thus to bring the subject gradually to order. Progress of this nature has been largely achieved in mechanical analysis. Since qualitative descriptions of soil textures can be expressed in terms of impersonal arithmetical quantities, the introduction of an approved international method of mechanical analysis is the logical outcome, and, it will be agreed, an advance of fundamental importance. It is earnestly hoped that, in all cases where the texture of the soil has to be considered, workers will give the figures obtained by the international method as well as those for the one they usually employ.

We may expect, in the immediate future, developments of work of direct interest to both the First and Sixth Commissions. The joint meeting held at Washington to discuss both the technical and physical aspects of dynamometer studies was an illustration; the subject of the soil drainage, which has both technical aspects and physical problems connected with the mechanism of water movement, is another case in point.

Developments of the nature indicated immediately above, and in the text of this paper, are the corollary of the more detailed and exact examination of the physical properties of soil that we may fairly claim has taken place in the past few years.

REFERENCES

(1) Abstracts First International Congress of Soil Science 1927.

(2) Agricultural Education Association of Great Britain 1906 Mechanical analysis of soils. *Jour. Agr. Sci.* 1: 470–474.

(3) Agricultural Education Association of Great Britain 1926 Mechanical analysis of soils. *Jour. Agr. Sci.* 16: 123–144.

(4) Briggs, L. J., and McLane, J. W. 1907 The moisture equivalent of soils. U. S. Dept. Agr. Bur. Soils Bul. 45.

(5) Coutts, J. R. H., et al. 1924 An automatic and continuous recording balance (the Oden-Keen balance) *Roy. Soc. (London) Proc. Ser. A.* 106 (No. A735): 33–51.

(6) Coutts and Crowther 1926 *Trans. Faraday Soc.* 21: 374–380.

(7) Fisher, R. A., and Oden, S. 1924 The theory of the mechanical analysis of sediments by means of the automatic balance. *Roy. Soc. Edinb. Proc.* 44: 88–115.

(8) Jennings, D. S., et al. 1922 A new method of mechanical analysis of soils. *Soil Sci.* 14: 485–499.

(9) Joseph, A. F., and Martin, F. J. 1921 Determination of clay in heavy soils. *Jour. Agr. Sci.* 11: 293–303.

(10) Krauss, G. 1922 *Proc. Third Internatl. Soil Cong.* (Prague); also *Internatl.* Mitt. Bodenk. 13 (1923): 147–160.

(11) Linford, L. B. 1926 The relation of light to soil moisture phenomena. *Soil Sci.* 22: 233–252.

(12) Oden, S. 1915 Eine neue Methode zur mechanischen Bodenanalyse. *Internatl. Mitt. Bodenk.* 5: 257–311.

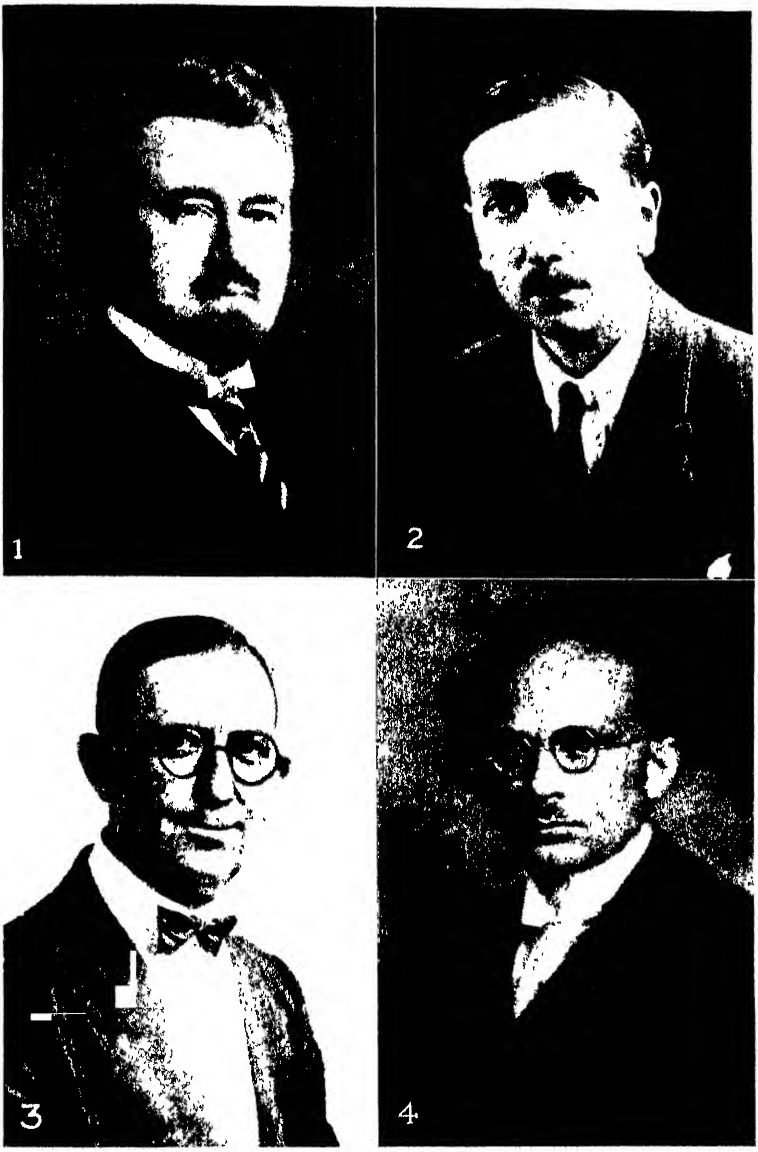
(13) Puri, A. N. 1925 A critical study of the hygroscopic coefficient of soil. *Jour Agr. Sci.* 15: 272–283.

(14) Puri, A. N., et al. 1925 Relation between the vapor pressure and water content of soils. *Jour. Agr. Sci.* 15: 68–88.

(15) Robinson, G. W. 1927 Note on the mechanical analysis of humus soils. *Jour. Agr. Sci.* 17: 287–291.

(16) Robinson, G. W. 1922 A new method for the mechanical analysis of soils and other dispersions. *Jour. Agr. Sci.* 12: 306–321.

(17) Wiegner, G. 1918 Über eine neue Methode der Schlämmanalyse. *Landw. Vers. Sta.* 91: 41–79.



FIRST COMMISSION

FIG. 1. V. Novak, Czechoslovakia, President.
FIG. 2. B. A. Keen, Rothamsted Experimental Station, England, Vice-President.
FIG. 3. R. O. E. Davis, U. S. Department of Agriculture, Vice-President.
FIG. 4. G. Krauss, Germany, Secretary (Copyright Harris & Ewing).

SECOND COMMISSION

SOIL CHEMISTRY

A. A. J. DE'SIGMOND

President

(Royal Joseph University of Technology, Hungary)

The Second Commission of the International Society of Soil Science, which treats the problems of soil chemistry, is one of the earliest international commissions, founded in 1910 by the Second International Conference of Agrogeology in Stockholm, Sweden. The present chairman was charged with the organization of the commission whose first aim was to find out the best methods of characterizing soils, with regard to their chemical properties.

The first meeting[1] of the Second Commission was held in Munich on April 23 and 24, 1914. The results of this meeting may be summarized as follows:

1. The meeting has decided, that though the hydrochloric acid extract of the soils does not give any absolute figures on the decomposed and undecomposed part of the soil, it gives a more definite idea of the rate of weathering of the soil than does the bulk analysis of the soil by fusion. On the other hand, comparative experiments with the different available methods indicate that it is difficult to find a natural limit to the rate of decomposition of the soil when hydrochloric acid is used in different concentrations and for different lengths of time. Therefore, the meeting suggested an agreement on a simple conventional method using concentrated hydrochloric acid for the preparation of the soil extracts to be analyzed.
2. Regarding the available plant-food in the soil, the meeting agreed to use the term "available" only in cases where plant physiological evidences prove the availability of the concerned plant food in soils. The plant-food question was thus limited almost entirely to the fields of plant physiological experiments.
3. The importance of base exchange and soil acidity was treated very extensively and some analytical methods were suggested for research work in this line.

At the Third International Conference of Pedology in Prague in 1922, the commission, disrupted by the war, was reorganized, and at the Fourth International Conference of Pedology all the lines of work which had been inaugurated at the first meeting of the commission at Munich in 1917, could be developed more extensively. Further details are given in the *Actes de la IVième Conference Internationale de Pedologie*, Rome, May 12–19, 1924, and as the decisions adopted at the conference are the starting points of the studies and discussions treated on the First International Congress of Soil Science at

[1] The preliminary reports of this meeting were published by the chairman in *Internatl. Mitt. Bodenk.* (1914) 4: 270. The report of the meeting itself was published as the "Protokoll der Tagung der internationalen Kommission fur die chemische Bodenanalyse," in the same periodical (1915) 5: 25.

Washington, June 13–22, 1927, the report of the meetings of the Second Commission will clarify the results of the previous convention.

The entire subject may be divided into the following departments of the Second Commission:

1. Plant nutrient in the soil
2. The acid extraction of the soil
3. Soil acidity and base exchange
4. Organic matter of the soil.

It is not the aim of this paper to give a detailed report of the numerous papers and discussions which were read at the five meetings of the commission, but rather to give the general scope of the results secured and the conclusions reached by the Second Commission, which were adopted by the Congress at Washington.

PLANT NUTRIENT IN THE SOIL

Though at the first meeting of the commission in 1914, it was agreed that the term "available plant-food" would be restricted to that part of the plant-food material in the soil which has been proved available by plant physiological experiments, still there is a steady demand on behalf of the farmers for prompt information concerning the plant-food requirements of their soils. Pot and field experiments require much time and are very expensive, therefore the soil laboratories are still burdened by inquiries about the plant nutrients in the soil. For this reason, the Second Commission again took up the question of laboratory methods of determining the plant nutrients in the soil and held a joint meeting on this question with the Fourth Commission. The total amount of of plant nutrients in soil must be distinguished from that part which is easily soluble in weak acids and which may be more or less available for plants. There are different methods for both parts, and in some instances practical conclusions can be drawn from these laboratory analyses. For example, the azotobacter test and certain chemical methods proved very satisfactory in the detection of lime and phosphoric acid-requirement. The Neubauer experiments may represent an intermediary physiological method between the chemical and plant physiological experiments, by which the phosphoric-acid and the potassium requirements of the soil might be determined. All these discussions indicate that more comprehensive and comparative experiments are necessary, to show which methods are most convenient and most practicable.

The Second and Fourth Commissions appointed a combined subcommittee consisting of D. R. Hoagland, Berkeley, California; O. Lemmermann, Berlin, Germany; and H. Niklas, Weihenstephan, Germany, to organize adqeuate experiments in the different countries, and to report at a subsequent meeting upon plant nutrients in soil and their analytical determination.

ACID EXTRACTION OF SOIL FOR ANALYSIS

The chemical composition of the hydrochloric-acid soil extract was widely used for the purpose of characterizing the chemical changes in soil which has been derived by process of weathering and leaching. In the classical work of E. W. Hilgard by this method striking evidences are presented as to the effect of climate upon the chemical composition of soils. Hilgard's method was based on the ultimate decomposing capacity of strong hydrochloric acid of a specific gravity of 1.115. The author himself has used this method very satisfactorily for the characterization of some Hungarian soils, especially alkali soils, and has proved by comparative analysis, that Hilgard's method gives almost the highest figures on the dissolved components in the acid extract. The method, however, requires long treatment and is likely to greatly decompose the unweathered soil minerals.

Van Bemmelen devised another method with the purpose of decomposing by concentrated hydrochloric acid only the so-called zeolitic part of the soil. This method was perfected by D. J. Hissink, and was accepted as a provisional method, by the Fourth International Conference at Rome in 1924. Only certain details required further experimentation. Eight different laboratory centers undertook the examination of these points on four different soil types; namely, Podsol, Rendzina, alkali soil, and "Badob" soil (Karthoum). The chairman of the commission reported the results of this analytical work and proposed the acceptance of a ratio of soil: acid = 1:10, and the time of extraction as 1 hour. Most of those present were in favor of this, but Ganssen spoke strongly in favor of the method of the Geological Institute at Berlin, by which about 10,000 soils already had been analyzed, emphasizing at the same time, that the van Bemmelen-Hissink method attacks the silicates too far, whereas by the Berlin method only the zeolitic part is decomposed.

After a long discussion it was agreed to adopt both methods tentatively, until evidence of the definite superiority of one of them is forthcoming. In order to organize the further study of this question a subcommittee was elected consisting of R. Ganssen, Berlin, Germany; J. Hendrick, Aberdeen, Scotland; D. J. Hissink, Groningen, Holland.

SOIL ACIDITY AND BASE EXCHANGE

The questions of soil acidity and base exchange were treated on the first meeting of the Second Commission at Munich in 1914. Special attention was given to both questions, which are closely related, at the meetings of the commission during the Fourth International Conference of Soil Science at Rome in 1924. Because of the great interest shown in this question, the late D. H. Christensen of Lingby, Denmark, and D. J. Hissink, of Groningen, Holland were appointed to organize and prepare all the questions related to soil acidity and soil absorption for the Washington Congress. For that reason a

SECOND COMMISSION

FIG. 1. A. A. J. deSigmond, Hungary, President (Copyright Erdélyi, Budapest.)
FIG. 2. G. Wiegner, Switzerland, Vice-President.
FIG. 3. O. Lemmermann, Germany, Vice-President.
FIG. 4. N. M. Comber, Leeds, England, Secretary.
FIG. 5. T. Saidel, Roumania, Secretary.
FIG. 6. M. M. McCool, U. S. A., Vice-President.
FIG. 7. E. Truog, U. S. A., Secretary.

special meeting of the Second Commission[2] was called at Groningen, Holland, from April 2 to 6, 1926, by a special commission consisting of A. A. J. de'Sigmond, Budapest, Hungary, as chairman and G. Wiegner, Zurich, Switzerland; N. M. Comber, Leeds, England; R. Ballenegger, Budapest, Hungary; H. R. Christensen, Lingby, Denmark; and D. J. Hissink, Groningen, Holland. The result of these meetings are reported as the Proposals of the Second Commission to the Washington Congress, adopted unanimously not only at the meeting of the commission but by the First International Congress of Soil Science at Washington in 1927. These conclusions of the Congress treat the following points with regard to the determination of soil acidity:

1. Preparation of the sample.
2. Experimental determinations, consisting of:

A. The determination of the reaction of mineral soils by determining the pH in aqueous and possibly in potassium chloride suspension; determination of hydrolytic and exchange acidity, buffer action, and exchangeable calcium.

B. Determination of lime requirement, including the buffering action in addition to the use of Daikuhara's method.

3. Details of the above mentioned experimental methods.

These agreements may introduce more uniform proceedings in the question of soil acidity for the future and may lead to more enlarged practical applications of the above mentioned determinations.

With regard to the soil absorption, more thorough studies are needed on the analytical methods used and suggested. In point 4 of the adopted proposal, we have pointed out only those methods which have been properly tested, up to the present time, for the determination of exchangeable bases and for the determination of the rate of saturation.

Finally, a general scheme of field experimenting has been adopted for the determination of lime requirement in soils in order that the above laboratory methods may be examined in their practical relations.

It is desired that more experiments in different countries be carried out on the same scheme to collect data from which conclusions may be drawn for the future.

To take care of this question a special subcommittee was appointed at the Congress consisting of: N. M. Comber, Leeds, England; D. J. Hissink, Groningen, Holland; O. Lemmermann, Berlin, Germany.

SOIL ORGANIC MATTER

As the soil organic matter is closely related to the soil population, at the Washington Congress the Second Commission treated this question in a joint meeting with the Third Commission on soil bacteriology.

To the present time, the organic matter has not been sufficiently treated by

[2] The transactions of this meeting were published in two volumes—vol. A, February 1, and vol. B., January 1, 1927.

the Second Commission, though the papers read at the Congress pointed out many objects of this line of work, which are of prominent interest with regard to the chemical characteristics of the soil In order to encourage and organize further studies in this line the joint meeting of the Second and Third Commissions has appointed a combined subcommittee of the members of both commissions consisting of: H. J. Page, Rothamsted, England; E. C. Shorey, Washington, D. C.; S. A. Waksman, New Brunswick, N. J.

At the end of the meetings of the Second Commission, the following officers were unanimously elected: *President:* A. A. J. de'Sigmond, Budapest, Hungary; *Vice-Presidents:* B. Armio, Helsinki, Finland; R. Ballenegger, Budapest, Hungary; K. K. Gedroiz, Leningrad, Russia; O. Lemmermann, Berlin, Germany; M. M. McCool, Michigan, U. S. A.; T. Saidel, Bucharest, Rumania; G. Wiegner, Zurich, Switzerland; *Secretaries:* L. Askinasy, Moscow, Russia; N. M. Comber, Leeds, England; G. Gorz, Berlin, Germany; W. H. McIntire, Tennessee, U. S. A.; E. Truog, Wisconsin, U. S. A.; Francis Zucker, Budapest, Hungary.

THIRD COMMISSION

Soil Biology and Biochemistry

RECENT PROGRESS

SELMAN A. WAKSMAN

Vice-President

(New Jersey Agricultural Experiment Station, U. S. A.)

Soil Microbiology is the science concerned, on the one hand, with the organisms present in the soil and, on the other hand, with the biochemical activities of these organisms, which may be beneficial or may even become injurious to the growth of higher plants. It is, therefore, within the scope of this science to determine the nature of the organisms present in the soil and their relative abundance under the influence of varying environmental conditions, and how the processes brought about in the soil by these organisms influence the contion of soil fertility. In the development of every science it becomes imperative to stop and reconsider the progress made, especially the bearing that it may have upon future lines of investigation. This is especially true of a science like soil microbiology, which draws for its advance upon many other sciences, notably the botanical, zoological, chemical, and physical, and particularly upon the methods used and progress made in general bacteriology and in the complicated subject of soils in its various phases.

Following the Fourth International Conference of Soil Science in 1924 in Rome, the author attempted to make a survey of the status of soil microbiology, especially in Europe and in the United States. The analysis thus prepared was purely subjective in nature and was based entirely upon personal observations of the author as a result of his contact with the various scientific workers at the conference in Rome and in a number of laboratories in some ten European countries. At the International Congress of Soil Science in Washington, forty or fifty scientists representing a score of different countries and the various sections of the United Stated met in a number of sessions to discuss the present day problems in soil microbiology and biochemistry. This paper is an attempt to summarize the present status of the subject of soil microbiology, based upon the papers presented at this Congress.

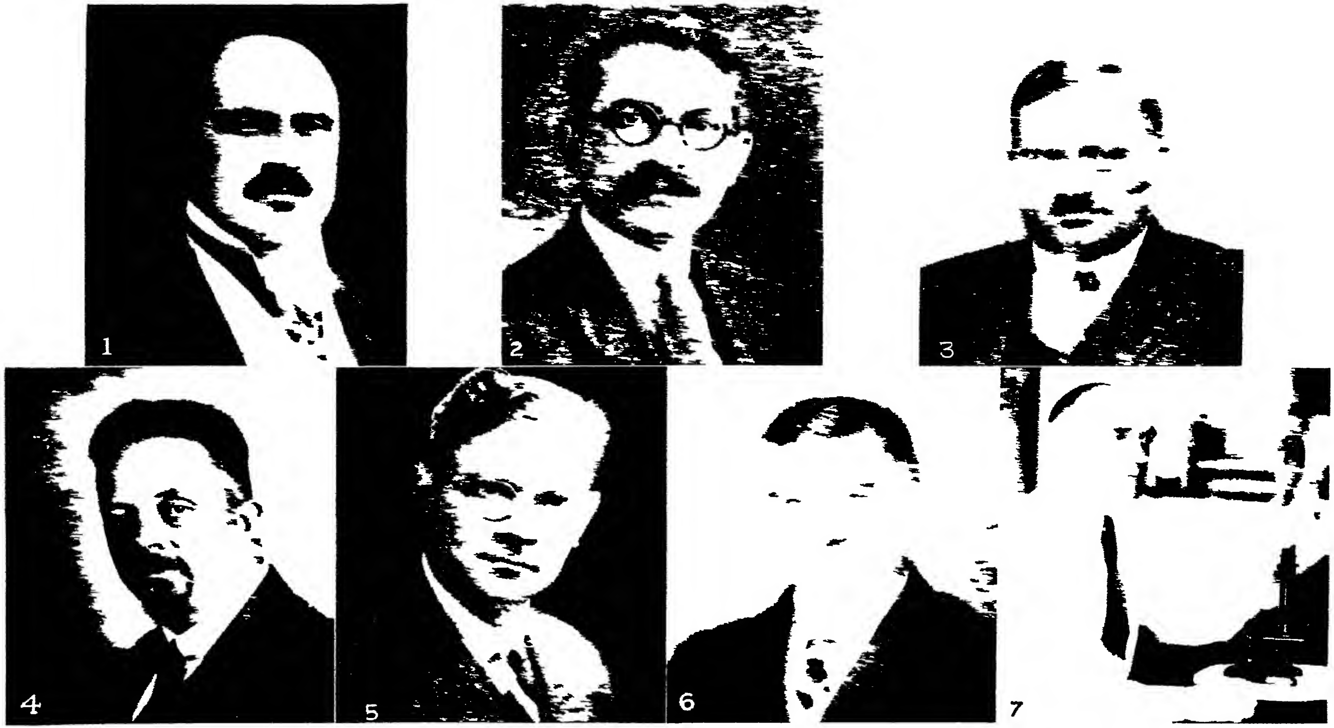
Had such a conference been held 15 years ago, the bacteria would have been the only soil organisms considered. At this conference, however, the soil fungi, algae, protozoa, and other invertebrates occupied a prominent place in the various papers and discussions. It has come to be recognized that the soil is inhabited by a definite population, which may vary both in numbers and in kinds depending upon the soil conditions. The various representatives of this

population take an active part in the numerous soil processes. It is relatively easy to isolate an organism from the soil and determine the specific biochemical processes which may be more or less characteristic of this organism. Whether simple media can be employed or highly specific media have to be devised, whether simple inorganic substances are utilized or highly complex organic materials are required, whether it is a rapidly growing organism or one that develops only extremely slowly, it can be cultivated sooner or later. Unfortunately, the soil chemist and biologist have started out first with a knowledge of certain specific processes taking place in the soil, such as the processes of nitrification, nitrogen fixation, and ammonia formation and, as ably pointed out by Winogradsky, "they have looked for organisms to account for the particular processes." The rest of the population was neglected. Many contributions have been made by botanists or zoologists who were interested in certain groups of organisms and who examined the soil as a substrate in which those organisms may be found. These investigators were little interested in soil processes as such. Few attempts have been made to develop methods of investigation which would be specific for the soil and its population.

Sooner or later, the organisms accounting for known soil processes have been isolated. It might have been a matter of simple technic, as in the case of the numerous fungi and actinomyces, ammonia-forming, nitrogen-fixing and other bacteria. It might have required considerable time and highly specific methods, as in the case of the nitrifying bacteria—or those organisms which are capable of obtaining the energy necessary for their life activities from ammonium salts or nitrites—and the aerobic and anaerobic cellulose-decomposing bacteria. The question of isolation in pure culture and cultivation of some of the organisms may still be a matter of dispute, as in the case of the numerous soil protozoa. Even now, however, when all this progress has been made and a number of specific organisms isolated and described, very little is known of the nature and activities of a large part of the complex soil population, as demonstrated directly under the microscope and as brought out by a number of artificial media. One of the most pressing problems in the study of the soil population is the development of direct and indirect methods for its study both in pure culture and in the soil itself, in association with the rest of the population.

A detailed discussion of the application of the direct method to the study of soil microorganisms is given elsewhere by Winogradsky (p. 37), where attention is called to the fact that most of our information on the soil population is largely a phase of general microbiology rather than of soil microbiology. The use of direct methods is suggested for studying the soil population in the soil itself, based upon the use of natural and spontaneous cultures of bacteria in the soil, and upon elective silico-gel plates. These methods are especially suitable for the study of nitrogen-fixing bacteria.

The direct microscopic method of studying soil bacteria, however, will



THIRD AND FOURTH COMMISSIONS

FIG 1 J Stoklasa Czechoslovakia, President of the Third Commission FIG 2 S A Waksman, U S A, Vice President of the Third Commission FIG 3 I H Niklas, Germany Vice President of the Third Commission FIG 4 E A Mitscherlich, Germany, President of the Fourth Commission FIG 5 D R Hoagland California Secretary of the Fourth Commission FIG 6 M Trénel Germany, Secretary of the Fourth Commission. FIG 7 E B Fred, U S A, Secretary of the Third Commission

hardly take the place of the plate method; it will only supplement it, as brought out recently by Conn.

In addition to the microscopic and cultural methods for studying the nature of the soil population, various biochemical methods are employed for measuring the sum total of the activities of the soil population as a whole. This has been brought out by Stoklasa, who demonstrated that the determination of the evolution of carbon dioxide from the soil can yield important results which have a direct bearing on soil productivity and give definite information concerning the rôle of soil microorganisms in these processes. This is of especial importance since the growth of plants is greatly favored by increasing concentrations of CO_2 in the atmosphere, this CO_2 being liberated through the activities of the soil microorganisms. A definite correlation has been established between the evolution of CO_2 from the soil and its productivity. Niklas called attention to the fact that the presence and concentration of various nutrients in the soil, such as available phosphates, can be readily determined by bacteriological methods, such as the Azotobacter test. The results obtained by this test compare very well with the results obtained by the Neubauer method and the actual plant growth.

The desirability of bringing about a greater uniformity of the methods used in soil microbiology has been emphasized in several papers (Lochhead, Bonazzi) at a special session which was devoted to the discussion of methods in soil microbiology. Because of differences in technique employed in different laboratories, the results of the quantitative determination of numbers of microorganisms and of the biochemical changes produced are comparable only to a very limited extent. Although it was admitted that the methods at present available are far from perfect and that many of these methods will be superseded by others with the progress of science, it was still felt that by adopting more uniform methods, greater collaboration between microbiologists and biochemists could be brought about. A permanent committee was appointed to consider the various recommendations made and to compare and study the different methods used in the mocrobiological analysis of soils.

The consideration of the nature of the soil population occupied a prominent place at the Congress. The following groups of organisms were discussed in detail in one or more contributions:

The distribution of algae in the soil, both on and beneath the surface. 2. The nature, abundance and activities of soil fungi including the mycorrhiza fungi, discriminating thereby those organisms which are present in the soil largely in the form of spores and those which form an abundant mycelium; the saprophytic and parasitic nature of fungi; the role of mycorrhiza in plant nutrition and in the evolution of the vegetable kingdom. 3. The heterotrophic and autotrophic soil bacteria, including in the first both spore-forming and non-spore forming types; the factors influencing the distribution of certain specific bacteria, like Azotobacter, in the soil. 4. The occurrence of protozoa in soils in different parts of the world, their relation to soil bacteria and their possible bearing upon soil processes; the protozoan population was found to run roughly parallel to bacterial counts (Sandon); however, the action of fungi was found to be greater than that of protozoa in affecting soil processes (Skinner). 5. The

occurrence of nematodes in the soil and their relation to the rest of the soil population and to the growth of higher plants. 6. The occurrence of phytopathogenic fungi in the soil. 7. The influence of soil treatment upon the biological activities in the soil.

In addition to the methods for the investigation of the soil microörganisms and the nature of the soil population, the various physiological activities of the numerous soil-inhabiting organisms and the rôle of their activities in soil processes have attracted considerable attention.

One may learn the specific physiology of an organism, determine how this physiology may fit into the system of soil processes, learn what organism or organisms are stimulated by the addition of a certain chemical substance to the soil, even be able to bring about the specific process in sterile soil by the specific organism, but it still remains to be found whether the particular process is carried out by the particular organism in a normal soil, under a normal set of environmental conditions, in the presence of a normal supply of available energy, in the presence of the numerous other soil organisms. It is sufficient to cite the case of the rôle of Azotobacter, or the aerobic, nitrogen-fixing organism in the soil. A whole literature has developed dealing with this organism alone; numerous claims appear frequently concerning the amount of nitrogen fixed by this organism under sterile conditions and presumably also under normal field conditions. There is not one valid claim, however, that this organism actually fixes nitrogen in a normal soil, with the sources of energy usually found in such a soil, and that it contributes in any way to the supply of soil nitrogen (Bonazzi, Brenner). The more recent contributions tend to indicate that this organism is much less numerous in the soil than the anaerobic *Clostridium*, that it cannot utilize the sources of energy introduced largely with the manures and plant residues, that, since under normal soil conditions the available energy supply is a much more limiting factor for the growth of microörganisms than the nitrogen supply (otherwise there would be no nitrates accumulating in the soil), Azotobacter will not develop and if it will, the soil nitrates will be utilized rather than the gaseous atmospheric nitrogen.

The problem of nitrogen-fixation in the soil received considerable attention, not less than 17 papers having been presented dealing with the non-symbiotic and symbiotic processes of the fixation of nitrogen. The nature of the organisms concerned in this process and their relation to the energy supply and the mechanism of nitrogen fixation received considerable attention. Plants were found, by secreting soluble organic matter, to influence markedly the fixation of nitrogen by bacteria. Fixation of nitrogen by anaerobic bacteria (*Cl. pasteurianum*) takes place within 2 to 3 days after inoculation and reaches a maximum in 10 to 15 days at 28°C. Among the butyric acid bacteria, those which produce acetic and butyric acids and do not ferment starch, are the most active nitrogen fixers (Fred). The fixation of nitrogen by Azotobacter is generally stimulated by the presence of soil protozoa, this favorable effect being ascribed to the buffering action upon the medium (Hirai and Hino).

On June 17, twenty-six members of the Third Commission, who were par-

ticularly interested in the study of the legume root nodule bacteria, met at the Cosmos Club for an informal conference. Representatives from sixteen states, the Department at Washington, and four foreign countries were represented. An expression of the wide variety of interests engaging the attention of the students in this field was very encouraging. Physiology of the organisms and their relation to practical agricultural practice seem to be stimulating the greatest amount of study. All of those attending felt that the informal nature of the discussions was very helpful and the wish was expressed that similar conferences could be held at future meetings of the scientific workers interested.

Considerable quantities of organic matter of plant and animal origin are added to the soil year after year. It is known that this organic matter decomposes in the soil, by the processes of so-called "decay" (aerobic decomposition) or "fermentation" (anaerobic decomposition), with a greater or less rapidity, depending upon the age and nature of the plant and the environmental soil conditions. A large part of the carbon is returned to the atmosphere in the form of CO_2 which is essential for the growth of higher plants. The first result of transformation of the natural organic matter added to the soil and the organic matter found in the soil, is a narrowing of the carbon-nitrogen ratio from about 80–25:1 to about 10-12:1, this being a direct result of the activities of the microörganisms in the soil. It is only when this has been brought about, or when the large excess of available energy over nitrogen has been used up, that the nitrogen can be liberated in the soil in the form of ammonia, rapidly changing to nitrates, a process which determines largely the growth of higher plants in this soil. Once this ratio has been established, the residual organic matter decomposes further only at a comparatively slow rate and is considered to be "humified" or to have become a part of the soil, as soil "humus." A correct understanding of the nature of these processes and a proper knowledge of the origin and nature of this soil "humus," which contains sufficient nitrogen to amount to 0.01 to 3.0 per cent of the whole mass of surface soil while the growing plant may actually starve for nitrogen, suggest to the scientist some of the most fascinating problems, which would prove of greatest importance in the practical and most economic utilization of the soil for the growth of cultivated and uncultivated crops.

Niklewski calculated that when nitrogen is added to the soil in the form of stable manure, only one fourth of it is readily available and is absorbed by plants; the rest of it is either changed into microbial protoplasm, or is leached out or is lost as gaseous elemental nitrogen. The rapid transformation of nitrogen from ammonia into microbial protoplasm is well defined in the fresh manure and may lead to plant starvation. Loss of nitrogen in the gaseous form can be prevented by suppressing the development of nitrifying bacteria. The nitrogen stored away in the microbial cells is readily made available as shown by the rapid formation of nitrates or by the decomposition of cellulose added to the soil, when the microbial cells are the only source of nitrogen (Barthel and Bengtson). Nitrogen is usually the limiting factor in the decomposi-

tion of fresh organic matter to the soil. When the plant contains about 1.7 per cent of nitrogen or more, the decomposition processes will be rapidly accompanied by the liberation of some of the nitrogen as ammonia, which is soon changed to nitrate; when the nitrogen content of the plant is less than 1.7, considerable time will elapse before some of the nitrogen will be liberated in a form available to higher plants (Waksman and Tenney). These results offer an interesting illustration in the utilization of organic residues and manures as sources of nitrogen for plants. However, when nitrogen is added to the soil in the form of an ammonium salt, without the addition of fresh organic matter, it is changed quantitatively to nitrates without any part of it being stored in the microbial cells or lost in a gaseous form (Hendrick).

An imperfect knowledge of the organic constituents of even our common cultivated and uncultivated plants, and a still more meagre knowledge of the composition of the microbial cells and the nature of the products resulting from their growth and decomposition account for our lack of knowledge of the origin of certain organic compounds in the soil (Shorey).

A series of papers dealing with the oxidation-reduction processes has received considerable attention. Clark presented the theoretical basis for the study of such processes. Blom demonstrated that in the reduction of nitrates both chemically and by microörganisms, the following products have been observed: ammonia, NO, N_2O, and N_2. Direct reduction of nitrates leads to the formation of nitrous acid, dioxyammonia, hydroxylamine, and ammonia; azooxyhydroxyl, hyponitrous acid, and dioxyhydrazine are formed as secondary reactions of the primary products; nitric oxide, nitrous oxide, and nitrogen are anhydrides of these compounds from which they are formed. The reduction of molecular nitrogen, or nitrogen fixation, can be explained by the same scheme. The oxidation of sulfur to sulfates, through the stage of hyposulfites and other intermediary products was demonstrated by Guittonneau. The precipitation of iron by bacteria, a process the physiology of which has always aroused considerable interest, was elucidated in two contributions by Lieske and Starkey and Halvorson. The solubility of iron compounds is affected by the hydrogen-ion or oxygen concentration of the medium. Precipitation of iron does not necessarily indicate an immediately preceding oxidation, and oxidation of iron may or may not result in precipitation. The existence of true iron bacteria depends upon their ability to accelerate a reaction which occurs spontaneously in the solution in which they develop. The precipitation of iron in nature may be of little significance biologically, unless the reactions responsible for the change are understood. Under anaerobic conditions, phosphates are reduced by microörganisms to phosphites, hypophosphites, and even phosphine; the presence of highly oxidized substances, such as nitrates and sulfates, retards the reduction of phosphates, nitrates being reduced first (Rudakov).

As a result of over forty years investigation in the field of soil microbiology, agricultural practice has been considerably modified. So much so that a

whole session of the third commission was devoted, at Washington, to "soil biology from an agronomic standpoint." The subject was broadly summarized by Sir John Russell of the Rothamsted Experimental Station, whose paper has been published elsewhere (2). The problems of decomposition of organic matter in the composting of stable manures, in the preparation of manure from straw and other plant residues and inorganic fertilizers (synthetic manures), and in green manures, especially from the point of view of the stage of the plant at which it should be plowed under; the fixation of nitrogen and inoculation of leguminous plants; the partial sterilization of soil by heat and antiseptics, thus controlling the soil population; the use of sulfur for control of certain plant diseases and for composting with rock phosphate; the microbiological analysis of soil leading to a determination of its ability to support plant growth all point to the various applications to agricultural practice of the results obtained in the soil with soil microörganisms and their activities.

The progress made in the study of soil microörganisms differs fundamentally from the progress made in the study of the physics and chemistry of soils, because of the very nature of the subject under consideration. Whereas the soil physicist, the chemist, and the geneticist can adopt certain methods of study and analysis, can agree upon general principles, and can profit greatly from collective work, from general routine procedures, the soil biologist has other paths to follow. The biologist and biochemist, dealing with life processes, is more of an individualist than the soil physicist, chemist, and geneticist; he has to depend more upon his own resources, work out his own methods, and suggest his own interpretation. So far from agreeing upon standard procedures, he is not even willing to admit that an attempt can be made at the present time to make uniform the methods of investigation and analysis. This matter was amply brought out in the first sessions of the Third Commission. The problems which face this commission are not of a nature that can be standardized. They are problems facing any group of investigators who attempt to unravel a series of complicated biological processes. What can be more complicated than the soil population and the numerous interrelated processes brought about by this complex population? In this respect any attempt at standardization may only hamper further progress.

The aim of the soil microbiologist is pure research, without any practical end point in mind. However, as a result of careful study and investigation, the practical application of soil microbiology to agricultural practice has been considerably advanced and placed upon a sound basis.

REFERENCES

(1) Abstracts of the First International Congress of Soil Science, Washington, D. C. 1927.

(2) RUSSELL, E. J. 1927 The present status of soil microbiology and its bearing upon agricultural practice. First Internatl. Cong. Soil Sci.

(3) WAKSMAN, S. A. 1925 Soil Microbiology in 1924: an attempt at an analysis and at a synthesis. *Soil Sci.* 19: 201–249.

THE DIRECT METHOD IN SOIL MICROBIOLOGY AND ITS APPLICATION TO THE STUDY OF NITROGEN FIXATION

S. WINOGRADSKY

Honorary Member of the Society

(Institute Pasteur, France)

The question as to whether we are justified in speaking of soil microbiology as of the youngest branch of microbiology has repeatedly been asked and differently answered. The writer is of opinion, already formulated in his address in Rome and elsewhere, that such a branch, if born, is yet in its infancy. What we call "soil microbiology" is not more than a chapter of general microbiology treating of microorganisms isolated from the soil and hypothetically admitted to be taking part in some processes which are characteristic of this natural medium. Remarkable work has been done in this direction by numerous investigators in many countries, and the accumulated knowledge of thirty-five years' work must be regarded as acquired scientific knowledge. Without doubt, it forms a necessary introduction to soil microbiology, *but it cannot be taken for soil microbiology itself.* The general topics of the two are too widely different to be considered under the same heading.

In fact, the subject of the general microbiologist is the study of the morphology and physiology of species which have been chosen by him or which have in some way fallen into his hands, whereas the aim of the soil microbiologist is to study the biological agents of soil processes, *such as they are given in nature*, in their original soil and under the special conditions of that soil. The former is free to use in his experiments all means suggested by certain standard programs or by his own ideas; but the latter has to pursue his investigations, as exactly as possible, in the boundaries placed by nature itself. In short, there is in principle the same difference between the two as between the agriculturist or horticulturist, on the one hand, and the florist or ecologist, on the other. This granted, it necessarily follows that aims so divergent cannot be served by one and the same method.

The writer will call attention to the two leading principles on which the highly elaborated methods of general microbiology are based. The first is the obligatory pure culture method. As far as the second is concerned, mention may be made of the plurality of conditions under which this pure culture has to be grown for the purpose of determining the reactions of a given species which are regarded as characteristic. These reactions such as the action produced by certain poisons, adaptations to chemicals, and influence of high temperature, may be quite impossible in nature. They are carefully studied,

nevertheless, inasmuch as they may lead to new variations or to industrial application, such as the production of glycerol from sugar by yeast or the formation of acetone and butyl alcohol by anaerobic bacteria.

Another point deserves consideration, since it touches the nature or reaction rather than a well-defined principle or method, namely, the use of laboratory collection cultures which were isolated or acquired previously and which have gone through numerous generations by transfers. Certainly, by keeping them in culture instead of isolating them freshly from soil, one saves time and labor, but one has reason to doubt whether these domesticated hothouse organisms can be considered to be identical with the soil species which they are believed to represent.

Imagine a microbiologist at work on some important soil process by the use of methods developed in general microbiology. Using the soil as an inoculum of a solution of a special composition, he tries to pass as rapidly as possible through the preliminary stage of crude or enrichment culture, and starts to isolate the organism, generally using a standardized solid medium. Conscious of the fact that only investigations with pure cultures are considered as trustworthy, the sooner he isolates these the better, for the proper study can begin only after the pure cultures have been isolated. Suppose he succeeds in reproducing in pure culture a certain amount of decomposition of some cellulose preparation—he has satisfied himself that he has isolated a cellulose-destroying bacterium from the soil. Is he justified in drawing conclusions? No. Even granted that the form isolated possesses some power of destroying some of the cellulose preparation *in pure culture*, nothing can be said concerning its specific activity *in the soil*, where it may come in contact with a physically and chemically different sample of cellulose, but chiefly where it may have to compete with a much more powerful cellulose-destroying organism, which attacks rapidly the entire energy source leaving nothing to the weaker organism. The cellulose-decomposing power of the latter can then be manifested only in pure culture, where it is not handicapped by competitors, and it remains in nature only as a potential cellulose-decomposing organism.

The data obtained by the pure culture method are rendered all the more fallacious by the fact frequently observed, that the most powerful agents are the most specific in their action, i.e., they are adapted to a much narrower range of conditions than the less specialized agents. The necessary consequence of this phenomenon is that the organisms which are of little or no importance in a particular process in nature can be readily isolated, whereas powerful agents which are probably the sole agents in transforming the energy material, are methodically overlooked on standard media. It becomes evident that even the most extensive and the most able application of the pure culture principle can lead to no other result than a more numerous collection of forms in pure state, concerning the rôle and rate of action of which in the soil one can have only a very faint idea.

What can be said then in regard to the aforementioned second principle,

i.e., the obligatory pure culture of an organism upon a series of media to obtain a series of reactions which are characteristic of the form isolated? The writer believes that these cultural manipulations—such as trying to grow typical soil microorganisms on milk, beef broth, broth gelatin, and many other "bacteriological media", standardized or not—are quite devoid of interest to soil microbiology. Such study may present an interest, as indicated, for the general microbiologist trying to get an insight into the plasticity of the organism, its variability, or the possibility of its function deviating—problems that have not much to do with its "wild" state. This is especially true, since the behavior of the respective pure culture could not be attributed to the original soil species, but rather to a cultural variety issued from the former through the special influence of a new mode of existence. Is it not evident, therefore, that the soil microbiologist, having plenty to do with the study of natural phenomena, should rather avoid questions of this kind at the risk of obscuring his own task?

These considerations lead inevitably to the perhaps somewhat startling conclusion, that the value of the above two principles of general microbiology become negative when applied to the special problems of soil microbiology; the procedure based on them appears to be unreliable and in some sense misleading. Logically then, there is no other solution than to consider these methods as auxiliary methods of no obligatory application to soil microbiology. On the contrary, principal stress must be laid on so-called crude cultures of an elective character, arranged in such a manner as to allow observation of the free play of all biological factors in a given soil. Investigations are to be carried out of course with "wild" species obtained directly from their original soil.

The writer is certainly not the first to criticize the current method. Incidental critical remarks can easily be found in the work of certan such leading soil scientists as Sir John Russell, or bacteriologists, as H. J. Conn. Conn deserves the credit for having pointed out the importance of adding a direct microscopic method to the exclusively cultural methods used in soil microbiology, and for devising a method for a microscopical examination of the soil. Too imperfect for experimental researches, this first method is nevertheless meritorious in having attracted attention to the question of biological soil microscopy, a subject completely neglected until very recently.

No serious attempt, however, was made to discover a general method less conventional and more adequate to soil problems than the current one, until the writer, after having briefly indicated in 1923–24 the basis of his so-called *direct method*, presented it in full detail in 1925.[1]

The general idea of this method is to keep conditions as nearly natural as possible. Consequently, no isolation, no pure cultures, no "bacteriological media" are admitted. The multiplication and activity of soil species, or

[1] *Ann. Inst. Pasteur.* 39: 299–354.

groups, are studied in the original soil itself, in provoking, by the addition of different substances or by physical means, the formation of so-called *natural* or *spontaneous cultures*, which are controlled by repeated microscopic examination, after a method devised by the writer. To secure the organisms in colonies out of the soil, *silica-jelly plates* of *an elective composition* are used, upon which particles of the soil samples studied are sown. The soil or the silica jelly, rendered elective by proper means, gives rise to a development of specific organisms so nearly exclusive, that the action observed can be attributed to them without doubt. If they are accompanied by other forms, there are means of determining the part played by them, if any.

A study of the reactions of one or more soil species in pure culture can, of course, be pursued if desirable, but the fact must be kept in mind that the potentialities thus established are not directly applicable to soil processes.

Such were the principles and the method devised in the writer's methodological researches. Now it seemed important to him to submit the new method to an extensive experimental trial in applying it to the study of a most interesting group of soil agents. He selected the nitrogen-fixing group and decided to proceed *ab ovo*, as if nearly nothing were known about it, using thereby the new procedure exclusively and putting totally aside the old one.[2]

At first the development of spontaneous cultures was brought about by adding small quantities of various energy sources to a fertile soil, which was then kept in a shallow stratum at optimum moistures and temperature, or was packed in glass cylinders, to obtain anaerobic conditions. Rapid multiplication of characteristic big cocci ensued in the first case, whereas innumerable Clostridium (Amylobacter) forms were found under anaerobic conditions. When evaluated roughly by the direct microscopic examination, the number of cocci attained in 48 hours was found to reach about a hundred millions and, after 24 hours more, 1½ to 2 billions per gram of soil. The exclusive predominance of the aforementioned cocci, as well as of the Clostridium was most striking.

The aerobic experiment was repeated, but, in addition to the carbonaceous matter, small quantities of nitric nitrogen were also added. The soil population presented at once a noticeably modified aspect. When the N:C ratio was 1:100 or somewhat more, the microscopic fields are found after 24 hours to be covered with numerous bacilli; though the cocci will slowly appear later, their abundance will hardly reach 1/25 part of the population formed without the addition of nitrogen. When the N:C ratio is raised to 25:100, none of the large cocci are formed, their resting stages not being numerous enough to be easily found in the preparations.

These observations lead to the conclusion that available nitrogen, even in the smallest doses, has the effect of inhibiting and suppressing the development of the characteristic cocci as if it were toxic to them. But of course, this is not

[2] This second memoire is published *ibidem*. 150 (1926): 455–520.

a question of toxicity, it is a simple consequence of the fact that the rate of multiplication of the bacilli is much more rapid than that of the large cocci, so that the latter are invariably depressed in all cases, where the ratio N: C is sufficient for the bacilli. Only when this ratio is reduced too low to permit the development of the bacilli, is the field left free for the more slowly growing cocci to pervade the medium in consuming the energy-bearing material.

What are these large cocci? Their apparent indifference to the presence of avaliable nitrogen suggests their nitrogen-fixing ability; their form and size resemble cultivated forms of Azotobacter, and they themselves are found to be soil Azotobacter forms, as can be easily demonstrated by isolating them from the soil.

The question arises, however, how one could explain the difference in the influence of nitric nitrogen on the soil Azotobacter and on the cultivated forms of this organism? The cultivated forms never show the highly characteristic negative reaction toward available nitrogen; on the contrary, they react to available nitrogen with an extraordinarily abundant growth, as was repeatedly noted. This is a new and instructive example of how different the behavior of a species in pure culture is from a natural form. In pure culture, safe from competition, the organism may be highly favored by the addition of a certain substance, which is used readily as a nutrient, whereas the same substance may become quite inimical in the soil, because it offers greater advantages to powerful antagonistic organisms, with whom the above mentioned organism has to compete for the available energy material. Facts of this kind are important, since they throw light on the decisive part that this competition plays in regulating the biological soil processes.

Except for this mode of spontaneous culture which is checked by microscopic examination, an easy method was devised for obtaining *macroscopic spontaneous cultures*, i.e., Azotobacter colonies on their own soil sample. Sifted earth containing 5 per cent pulverized starch is worked with little water to a thick paste, then packed into small 5-cm. Petri dishes; the surface is polished with a glass slide moistened with water and the plates are incubated at 30°. Where Azotobacter is present, colonies will appear after 48 hours, rarely later, in nearly pure state, covering the surface of the soil plate more or less densely.

Passing to the plate cultures on elective silica-jelly, Petri dishes of different dimensions are used:

1. Plates 9 to 10 cm. in diameter are inoculated with 50 or 100 smallest grains of soil deposited on the surface of the jelly; these plates are convenient for rapidly discovering the presence of Azotobacter in the soil.

2. Large 20 cm. plates for determining the density of Azotobacter cells in a given sample of soil and at the same time its "power of nitrogen-fixation"; the plates are inoculated with 1 gm. of soil, on a dry basis, incubated the necessary length of time, then dried and digested by the Kjeldahl method.

The Azotobacter colonies appear after 48 hours incubation, sometimes followed by Clostridium species, which later develop under the cover of the Azotobacter slime. In the absence of both the aerobic and the anaerobic groups, there is practically no fixation of nitrogen, even if some "oligonitrophilous" colonies are present. Generally, the writer did not succeed in finding in soil other nitrogen-fixing organisms except the above named. This suggests that the number of species, relatively numerous, described as fixing nitrogen *are not natural fixing agents*, although able to develop some power of fixation under the influence of artificial laboratory conditions.

The method of "large plates" presents decided advantages and proved to give results more accurate and constant than those of fixation experiments under other conditions.

1. The nitrogen-fixing flora of the soil sample develops all over the surface of the plate in the form of colonies or of centers of vegetation, which are easily determined both in quality and quantity. The direct count of the colonies gives the density of the cells, namely, their number per gram of soil. This dose, if sampled *lege artis*, appears as truly representative of the respective nonsymbiotic nitrogen-fixing flora.

2. The activity of "the biological nitrogen-fixing apparatus" coming directly from soil, unmodified, therefore, by cultural manipulations, shows within experimental limits a value more constant than was previously ever attained by using pure cultures.

3. The constant yield of fixed nitrogen under these conditions renders possible establishing a *normal or standard process*, without which the determination of the activity of different soils can never be managed on a reliable basis.

4. This activity must and can be characterized not only by the absolute gain or by the yield of nitrogen per unit of energy source but chiefly by the *energy of the process*, namely, the time necesssary for a determined gain; this period of time certainly depends on the density of the cells and their activeness. By a number of concordant experiments with samples of different origin, it was established that an active soil, in fixing 20 mgm. of nitrogen, decomposes 2 gm. of mannitol in 5 days (120 hours); this makes 1 part of nitrogen fixed for 100 parts of mannitol (or glucose), or 1 part of nitrogen per 40 of organic carbon.

To determine the so-called "power of fixation" of soils, standard mannitol solution was universally used during a period of twenty years. The method is certainly untrustworthy in negative cases, and it is quite incapable of yielding the slightest information concerning the density of Azotobacter cells and their state of activity in the natural soil. The method may retain its historical value, but it is about time to replace it with more perfect methods, such as the spontaneous culture and the silica plate methods, which are to be used *simultaneously;* the former giving indications chiefly concerning the activity and the latter concerning the density of the population.

These two characters are not necessarily parallel, as it might seem. Soil samples are frequently found which show on elective silica plates the presence of relatively numerous cells, but they refuse to give spontaneous cultures after addition of some mannitol. This fact is important, since it shows that Azotobacter germs, viable and easily developing on a suitable medium *out of the soil,* keep obstinately at rest *in the midst of this soil.* What other interpretation of

the fact can be suggested than that the soil has become infertile toward the nitrogen-fixing flora that it harbors? It is evident, there, that a soil containing an inactive specific flora cannot be considered as active. On the basis developed above, four categories of soils may be tentatively established:

1. *Soils very active:* These give in 48 hours at 30° rich spontaneous cultures, both microscopic and macroscopic. On the large plates they show the maximum number of centers of vegetation of Azotobacter (2500 to 3000). They attain easily the standard gain of nitrogen in 120 hours.

2. *Soils not very active:* These give slower spontaneous cultures, which are considerably less abundant, and form on large plates about a hundred to a thousand centers. They show a gain slightly but constantly lower than the first group of soils.

3. *Soils temporarily inactive:* They give no spontaneous cultures of any kind, and form on plates a few to some hundred centers. The gain in nitrogen is inferior to the standard of 10 per cent or more.

4. *Soils permanently inactive:* These give no spontaneous cultures of any kind and no Azotobacter colonies on plates. They give no gain of nitrogen, or mere traces not exceeding some decimilligrams.

The writer believes that to get information concerning their state of activity, it may prove useful in practice to submit soils to periodical tests by means of these rapid and easy methods. Agriculturists avoiding microscopic work might use the starched soil plates, which give nearly parallel results with the microscopic method.

Still further conclusions can be drawn from these methods. The existence of soils not very active and temporarily inactive—that is, soils harboring cells but giving them no fair chance of development—raises the question concerning the means of restoring to them the lost activity.

Decisive results were obtained with the addition of soluble phosphates and of carbonate of lime. A set of experiments soon to be published, has shown especially that in soils where the scarcity of available phosphate is the limiting factor, there is no easier and sharper method of indicating it than that of spontaneous cultures of Azotobacter.

The writer hopes that the general conclusion of this extensive trial of the direct method is that it will be more widely applied, as promising a nearer approach to biological soil problems and a more effectual contribution therefore to the soil science than the actual standard methods.

Whether it be equally convenient to apply it to groups less characteristic than the above treated, remains to be seen. In all cases, however, where this application will not meet with serious difficulties, the method can be expected to lead not only to hypothetical or conventional, but to more real knowledge.

FOURTH COMMISSION

SOIL FERTILITY

D. R. HOAGLAND[1]

Secretary

(University of California, U S A)

The arrangement of the program of the Fourth Commission was considerably handicapped because of the greatly regretted absence of the president, E. A. Mitscherlich and of the vice president, K. Zylstra. Fortunately, M. C. Trénel of Berlin came as a representative of the president. At the opening session of the Congress, Trénel referred briefly to the meeting of the Fourth Commission held in Düsseldorf on June 21, 1926. At this meeting a general discussion occurred concerning the various chemical and physiological methods of evaluating the ability of a soil to support the adequate growth of crops. Among the methods may be mentioned those of Mitscherlich and Neubauer-Schneider. Trénel reported that no definite or clear conclusion could be arrived at, and expressed his opinion that no solution of the questions involved could be hoped for at the present time, in view of the extreme deficiency of our knowledge concerning the internal chemistry of the plant. In stressing the extraordinary difficulties presented by the problems of the Fourth Commission, Trénel at the same time expressed the idea that from a broad point of view these problems of soil and plant relations were the most vital ones under consideration by the Congress.

Because of the very broad scope of the interests of the members of the Fourth Commission it was natural that its members should be deeply concerned in the discussions of most of the other commissions and especially in those of the Second Commission. Therefore it came about that only one independent session of the Fourth Commission could be arranged. One session was held jointly with the Second Commission. At this latter meeting A. A. J. de Sigmond gave a resumé of the methods now in use for studying the nutrient elements of the soil, and made certain recommendations for future investigations. These proposals will be discussed under the report of the Second Commission.

Many papers were submitted to the Fourth Commission which could not be read at either of these sessions, and of those papers which were read only a few

[1] Only a few of the speakers furnished the secretary with notes of their remarks. This report, therefore, should not be considered as a complete and accurate record of the informal discussions which took place, but is intended rather to give a general impression of the nature of the activities of the Fourth Commission. The formal papers will be printed in the Proceedings.

could be discussed. Since the same situation may be expected to arise at future meetings of the Fourth Commission, the suggestion was made that hereafter the programs should be limited to symposia in which prearranged topics for informal discussion would be introduced for a few invited speakers. All other papers would be presented by title and abstract, and later printed in full in the Proceedings. It may be added that in the case of the present Congress, the formally announced meetings were supplemented by several very informal round-table disussions held by smaller groups at the Cosmos Club. This type of interchange of experiences and of speculations was very profitable and no doubt will tend toward a better mutual understanding of the results of research which may be published in the future by the participants in these conferences.

The independent session of the Fourth Commission was held on Wednesday afternoon, June 15. At this session the subject under review was "Soil and Plant Relations with special reference to the Soil Solution". After the reading of papers by Burd, Parker, Hoagland, Niklas, and Farr an extended general discussion took place. One valuable result of the interchange of ideas was the conviction that various misunderstandings in the literature had arisen because of divergent meanings attached to common expressions. For example, the term *soil solution* was interpreted in various ways. According to one view it was held that the solution intimately in contact with a root surface should not be called a *soil solution*. On the other hand, certain speakers in referring to soil solutions placed no such limitation on the meaning of the term.

In the first paper J. S. Burd made a very brief statement with regard to the soil solution investigations carried on in California over a long period of years, emphasizing several aspects of the work to which attention had been given most recently. It was pointed out that in California most of the experiments have been made on neutral or alkaline soils, whereas in humid regions analogous experiments have been concerned generally with acid soils. In this connection, buffer effects are of importance. The mechanism ot solution is not fundamentally different in the two types of soil (in both cases the biological production of acids is essential), but because of the nature of the solid phase in many arid soils, the effect of the formation of acids is to maintain high concentrations of most solutes in the liquid phase without measurable changes of hydrogen-ion concentration. The importance of studying the solid phase of soils, particularly in the case of soils tending to maintain very low concentrations of solutes, was emphasized. It was suggested that one of the most fruitful means of accomplishing this purpose is to examine soils which have been so treated with acid as to produce changes in hydrogen-ion concentration comparable to those which may occur under natural conditions. Both phosphate and potassium should be studied in this manner.

F. W. Parker reported experiments on phosphate which indicated that in many soils from humid regions the concentrations of phosphate found in displaced solutions were so low as to open to question the adequacy of such con-

centrations to produce the crop yields actually obtained on these soils under field conditions. Solution culture experiments seemed to support the view that the displacement solutions did in fact contain phosphate in concentrations too low for the requirements of at least several types of plants. Furthermore, the total phosphate of the displaced solution was not found to be absorbable by the plant, but only the inorganic fraction, as determined by the use of the colorimetric method. The conclusion was reached, therefore, that some mechanism closely associated with the solid phase must be taken into account. A similar situation was thought to exist in the case of iron, but possibly other elements fall in a different category.

D. R. Hoagland reported the results of experiments with large-celled algae and with agricultural plants, which seemed to illustrate a general principle of plant nutrition, namely, the absorption of mineral elements is logarithmic in character, which permits a high degree of adaptation by plants to solutions of low concentration. The absorption is not a simple matter of permeability but is bound up with the activities of the living cell. The extraordinary difficulty of fixing the magnitudes of critically low concentrations in a culture medium was pointed out. The solid phase of the soil as related to "supplying power" for potassium was discussed with reference to recent California investigations on soils in which physiological deficiencies of potassium apparently occur. In this connection consideration was given to the importance of replaceable base potassium, and of the fixing power of soils for this element. Concerning the comparative absorption of mineral elements by different types of plants, mention was made of recent experiments which showed that although different plants had more or less similar general effects in lowering the total concentration of the soil solution, quantitative confirmation was obtained for the commonly held idea that they may react characteristically in their withdrawal of certain mineral supplies initially present in the solid phase. In experimenting with a wide range of plant types and of cultural conditions, however, no consistent specific relationship such as that between calcium and nitrogen, or calcium and phosphorus could be demonstrated to govern the absorption of chemical elements.

H. Niklas reported and discussed the results obtained in a series of experiments, carried on in Germany over a period of twelve years, dealing with the effects of potassium fertilization on certain German soils. These investigations were not confined to determinations of the effects of fertilizers on crop yields. Various special studies were made on the physical and chemical properties of the fertilized soils, as well as certain chemical examinations of the crops. The microorganisms of the soil were also subjected to study. It was not found that the addition of potassium fertilizers had any significant effect on the reaction of the soils in question, nor did the continued use of potassium fertilizers develop any permanently unfavorable influence on their physical state. Observations were made on the reaction of juices from plants representing the various types of crops used in the experiment, which yielded the

information that the pH values for any given crop were fairly constant during the growth period, but different types of plants showed significantly divergent values in this regard. No marked influence of the soil reaction on the reaction of the plant sap could be demonstrated, but the buffering power of the sap of plants grown on acid soils was less than that for plants grown on neutral or alkaline soils.

C. Farr presented an interesting paper on the rate of growth of root hairs as affected by calcium-ion and hydrogen-ion concentrations. Three dimensional models were shown to illustrate the interdependence of Ca and H ions in influencing root hair development. The conclusions reached had a very direct interest in connection with soil solution studies on either acid or highly alkaline soils.

Following the reading of the papers, an hour of general discussion took place, which was participated in by Page, Goerz, Parker, Burd, Hoagland, Fraps, Farr, McIntire, Truog and several others.

The nature of the relation between root hair and soil particle received much comment. Truog emphasized the view that plants are probably not dependent entirely on the soil solution, but that the intimate contact of root hair and soil particle—sometimes called a *growth fusion*—creates in a sense an independent system from which plants absorb, or *feed*, independently of the soil solution. In this system, carbonic acid acts at maximum efficiency because of its immediate contact with exposed surfaces and also because the soluble products are quickly absorbed. In subsequent informal discussions Comber also commented upon this view, which was similar in part to one he had proposed some years ago. Parker likewise felt that his results on phosphate absorption were not compatible with any simple soil solution theory, as far as phosphate was concerned. It appeared that very striking differences might exist between soils from different regions with regard to the particular concentrations of PO_4 in the displaced solutions. These differences reflect a condition satisfactory for plant growth. Page referred to certain English soils, and Burd to a group of California soils, comparing them with the soils from Alabama and other states described by Parker.

No really serious disagreement existed among the speakers regarding the aspects of the soil plant system. No one was disposed to argue that the solid phase of the soil should be disregarded; indeed those especially interested in soil solution studies strongly emphasized the undeniable fact that the replenishment of the liquid phase of the soil from solid components (*renewing power*) was a vital consideration in all researches in this field. There was also a general assent to the view that the intimacy of the union between root and soil particle was of great significance, but after this statement was made, the discussions generally entered the realm of pure speculation. The need for experimental data of a direct microscopic or ultra-microscopic type was evident, but no suggestion of a means for obtaining such data was forthcoming. Although serious consideration was given to the colloidal system constituted by soil

particle and root hair, there appeared to be no objection to the view that in general, fertile soils tend to maintain higher total concentrations of solutes in the soil moisture than do infertile soils.

Concerning the rôle of carbon dioxide in soil solution processes, the differences of opinion which existed may have arisen merely because the soils investigated differed in their reaction, buffer effect, and calcium content. It was manifest in this instance, as in many others, that much would be gained if all investigators could utilize more frequently a wide selection of soils in testing out methods and hypotheses.

Trénel stated that in Germany there is less concern about the composition of soil solutions, inasmuch as the availability of the mineral elements of the soil is determined by the method of Neubauer-Schneider or that of Mitscherlich. In the former method the seedling itself reflects the ability of the soil to supply phosphorus or potassium to the plant. On this point it was remarked by one or two speakers that however useful the Neubauer method might be as an aid in the appraisal of soil deficiencies, it could not elucidate the nature of the fundamental relations involved.

Another general topic upon which opinions were heard dealt with the soil's content of replaceable potassium in relation to the absorption of this element by the plant. It was apparent that notwithstanding the great development of researches on base replacement, the physiological interrelations, apart from those of alkali soils had received highly inadequate attention. Page referred to certain interesting data on the Rothamsted soils pertaining to replaceable potassium, and stated that no conclusion was yet available in respect to the possible interconversion between replaceable potassium and potassium in less active forms. Truog was of the opinion that some evidence indicated that potassium, at least in part, goes over into a more insoluble form subsequent to its fixation as a replaceable base in the colloidal complex. For that reason, small, frequent applications of potassium fertilizers may be desirable. MacIntire also made the comment that some of the potassium fixed by a soil may be fairly available to plants whereas some of it may be rendered relatively insoluble. This is in accord with the parallel case of calcium and magnesium, which may become progressively less soluble, as was found at the Tennessee Experiment Station. However, the development of root hairs may be enhanced by certain treatments, for example, by the addition of lime to some soils and thus the plant may be able to obtain larger supplies of potassium, and to overcome to some extent any repression in the solubility of this element.

Fraps spoke of the very extensive experience he had had with the fifth-normal nitric acid method for estimating the active potassium present in soils. The number of soils investigated was very great and the results were therefore amenable to statistical treatment. A very high degree of correlation was found between the amount of potassium extractable by fifth-normal nitric acid and the amount capable of absorption by plants. The same investigator, in later comments on soil solution work, stressed the undersirability of using the

term *optimum* to designate some specific moisture content of a soil, more or less arbitrarily selected.

In surveying the discussions of the Fourth Commission it is noted that no radically new suggestions were advanced for studying the relationship of soil and plant. It is an interesting observation also that some of the most fruitful opportunities for future effort seem to be found in modern elaborations and developments of much older ideas. One may cite, for example, phenomena associated with base exchange, the effect of acids on soils simulating natural conditions, the use of plants as indicators of the potentialities of soils to supply essential elements to plants, the displacement method for obtaining soil solutions, and the growth of plants in water cultures. Hydrogen-ion measurements and buffer effects were recognized to be extremely important, but these conceptions also have long been under discussion. McHargue, in a paper given at another session, drew attention to the insufficiently appreciated necessity for realizing that plants require for their normal growth other chemical elements in addition to the classical ten, but in this case as well, we can look backward a good many years to the early work of Mazé.

Although no striking discovery or entirely new plan of attack was announced before the Fourth Commission, there was no cause for discouragement. In every instance the reports of the various investigators made it plain that only a beginning had been made in the use of sound methods and conceptions, and that the researches reported could be continued profitably over a long and indefinite future period. There was every reason to suppose that a far more satisfactory understanding of many perplexing problems could be reached by the persistent and thorough utilization of methods of investigation already at hand. In one field of research, that of plant physiology, it might be questioned whether there was evidence of an activity commensurate with the requirements of a commission organized for the purpose of deliberating on questions always physiological in their ultimate purpose, and often very immediately concerned with the metabolic activities of the plant. It would seem that it might be appropriate for the Fourth Commission to undertake to relate in a more intensive way the work of the plant physiologist and that of the soil chemist. Naturally any such endeavor would not be restricted to practical problems of agronomy or horticulture.

FIFTH COMMISSION

CLASSIFICATION, NOMENCLATURE, AND MAPPING OF SOILS

C. F. MARBUT

President

(U. S Department of Agriculture, Bureau of Chemistry and Soils)

The Fifth Commission is charged with the duty of promoting not merely the work of classification, nomenclature, and mapping of soils, but the study also of soil genesis, development, and morphology.

Although the broader scope of the work of this commission is not stated in its title, it is clearly included, because scientific classification of any series of bodies is impossible except on the basis of their characteristics. Classification is necessarily preceded or accompanied by the determination of the genesis and morphology of the objects classified, and the determination of the latter constitutes the research work of the commission, whereas the former consists of a mechanical operation based on the results of the latter.

To a still greater extent is nomenclature dependent on the results of the research work in genesis and morphology, the summation of the accomplishments of the latter up to any given time, and the creation of the units which must be classified and named. The classification and the naming of the individual bodies and groups of bodies are correlative in their fundamental nature, neither consisting primarily of research but both based on its results.

Similarly, mapping is dependent entirely on the research work in genesis and morphology, since this cannot be done until units or individuals have been defined. This is dependent wholly on research though not necessarily dependent on nomenclature nor even on classification except in a very limited way.

A commission on classification and nomenclature of soils was first appointed on the motion of Murgoci at the Extraordinary Conference of Pedology held in Prague in April, 1922. At a previous conference, that held in Stockholm in 1910, a commission was created and charged with the duty of constructing a scheme for the classification of the soils in the Morainic region of northwestern Europe. This commission was assigned to the task thus limited in its range of work presumably on the assumption that the Russian scheme of classification covered the rest of Europe. Frosterus was made president of the commission. It covered in its work soils of Sweden, Norway, Denmark, and Finland. Two meetings of representatives from these countries were held prior to the meeting of the Rome Conference in 1924, one in 1921 and the other in 1923. Between 1910 and the outbreak of the World War, no meetings

were held but some fundamental investigations on soil morphology in the region were carried out by the president. In this work Frosterus was able to define for the first time in a European language, and to fix with names, the concept of *The Soil* and *The Soil Material* or *parent material*. He was able also to subdivide the Podsol soils of Finland into Humus Podsols and Iron Podsols. At the conferences of the Scandinavian countries in 1921 and 1923 it had been agreed to classify soils on the features of their profiles but it seems that no scheme was proposed by which the soils of the whole region could be grouped into a series of categories on the basis of the various important profile features. It is impossible to classify a series of bodies on the basis of their characteristics without constructing a scheme with a series of categories in each of which the individual bodies are grouped on the basis of one or more characteristics common to the bodies in the group. If this be not done the classification must be stopped at the beginning—at the point where units have been defined but before any unit grouping (the essential feature of a real classification) has been begun. It is apparent, therefore, that the chairman of the commission in his work on soil morphology developed some clear and highly significant conceptions but that in the work of classification little progress was made.

Frosterus did not attend the Prague Conference and presented no report, but he was named president of the commission for soil classification with no limitation on the scope of its work. It was authorized to study soil classification applicable to the entire world. A commission on the catography of soils was created at the Prague Conference, and Murgoci was appointed President. Both commissions were world wide in their scope, this being the first time in the history of pedological science that such commissions had been definitely created with authority to deal with the subjects from the scientific standpoint without geographic limitation. Both commissions presented elaborate reports to the Rome Conference in 1924. The presidents of both attacked the problem from the same standpoint. These being the first reports of any such commissions it was logical to determine and present to the Conference the actual status of soil classification and nomenclature, on the one hand, and soil mapping, on the other, in the various countries of the world. Specialists in each country were requested to prepare full reports on the status of the work in the respective countries.[1] Frosterus presented a report, previously published by the Geological Survey of Finland containing papers describing the classification schemes in use in all the countries of Europe excepting Yugo-Slavia, Italy, Spain, Greece, Bulgaria, Switzerland, and Belgium, and including one country, Egypt, in Africa. It included no papers from any Asiatic, North American, South American or Australian country.

The Frosterus report contains 24 papers. It is manifest that most of them must necessarily concern the classification of the author's home country without any attempt to broaden the scheme so as to include all soils. It is equally

[1] It is apparent that no request was presented to anyone in the United States for a statement regarding the classification and nomenclature of soils then in use in that country.

manifest that the ultimate and desirable goal of soil classification is to construct a scheme broad enough to include all soils and to place the soils of each country into such a scheme. Until such a universally inclusive scheme has been constructed, each country must construct its own local scheme. The construction of a broadly inclusive scheme can be effected only by persons who have broad experience, and in the early stages of the development of a science like that in which pedology now stands, few persons have had such experience.

Four papers in the Frosterus report—those by Till, Stremme and Aarnio, Murgoci, and Glinka[2]—contain the results of an attempt to construct a scheme broad enough to include all soils. The rest of the papers are local in their range and no effort is made to fit them into any universal scheme except, in some cases, the Russian scheme. Most of them are based on the geology of the materials from which the soils have been developed.

The paper by Till, in so far as it concerns the classification of soils, on any other than the texture basis, groups soils as follows: 1. Soils without true soil profiles, 2. Soils with incomplete profiles, 3. Soils with fully developed profiles, 4. Soils with fully developed but not well maintained profiles. Under each of these major groups he constructs a number of sub-groups giving his scheme two categories.

The scheme is incomplete. A moment's thought will convince the specialist that a complete scheme must provide a category for those features or characteristics which result from the action of each of the great soil forming conditions and forces. There are more than two of these conditions and forces.

The major groups in Till's scheme are based on fundamental soil characteristics and to that extent the grouping is sound, but his groups are not comparable. They are not related in either characteristics or causes. Soils without profiles differ from those with fully developed profiles not merely in the action of a different kind or phase of the same force or condition—such, for example as a different kind of rainfall, temperature, or surface relief—but one is due to one cause, the other may be due to an entirely different and unrelated cause.

The scheme prepared by Murgoci is fundamentally similar to that by Till. He bases his major grouping on the degree of perfection to which the profiles of the included numbers have been developed. He also has built a scheme with two categories, and the bases of his major groupings are not comparable. In both cases, however, the basis for each of the major groups is a real soil basis and the scheme is to that extent much more scientific than the old major grouping on a geological basis.

Another objection to the major groups in both schemes is that they have no

[2] Bodenklassification und Systematik, von Alfred Till, Wien, Oestriech.

Zur Frage der Bodenbeldung und Bodenklassifikation, von B. Aarnio und H. Stremme.

Considerations Concerning the Classification and Nomenclature of Soils, by G. Murgoci, Bucarest, Roumania.

Differents types d'Apris lesquels se forment les sols et la classification de ces dernieres, par K. D. Glinka, Petrograd, Russia.

systematic relationship to the geographic environment under which the soils included in them exist and, therefore, cannot be expressed geographically. If the Russian zonality of soils is fundamental and universally applicable, and the opinion that they are is practically universal among modern pedologists, it is illogical to construct schemes of classification in which zonal and azonal soils are placed in comparable groups.

The paper by Aarnio and Stremme attempts to construct a scheme for the classification of soils on the basis of the character of the mobile salts present. Their major category includes three groups: 1. Sesquioxide soils, 2. Carbonate soils, and 3. Soils with water-soluble salts.

They do not attempt to develop a complete scheme with a number of categories varying in the number of soil units included and each based on the characteristics produced by a given cause or condition, but devote themselves to the work of establishing their major categories on a chemical basis by bringing together a great number of chemical analyses of soils from soil literature and grouping them under the respective categories showing thereby the chemical characteristics of each group. In addition to the fact that the scheme prepared by them is incomplete because of its limitation to a single category, there are other objections that may be raised against it. Insofar as the available data go, it is clear that they have shown that it is possible to group soils as proposed by them, and the grouping has been established on a thoroughly sound basis. The groups are not comparable, however. It is not maintained by the authors, however, that these groups should constitute a single category in a comprehensive scheme. If, therefore, a complete scheme were constructed, it is possible that each of these groups would find a place in it in some of the categories. In addition to the criticism of the scheme because the groups are not comparable, strong criticism may be made of the inclusion of widely different soils in some of the groups. The inclusion of the Rendzinas, for example, in the same major group as the Tschernosems cannot be justified. It is well known that many Rendzinas belong with the Sesquioxide group, whereas others may belong in the same major group with the Tschernosems but in a sub-group under the latter. The grouping of all Salzböden into groundwater soils may well be questioned also. The Laterites, if they be defined as soils characterized by an intensive segregation of the sesquioxides, especially of iron, seem to belong more nearly in the groundwater group than elsewhere.

The last paper of the four attempting to classify all soils rather than those of a given locality, prepared by Glinka, consists of a brief statement of the Russian point of view. He divides the soils of the world into five great groups or, as he calls them, types as follows: 1. The Laterite type, 2. The Podsol type, 3. The type of the Steppes, 4. The Solonetz type, 5. The Marsh or wet land type.

As in the other cases, he does not attempt to construct a complete scheme of soil classification but contents himself with arranging all soils into several groups constituting a single category with, in a few cases, a limited subgroup-

ing. No pretense is made of presenting a complete scheme including all categories. He presumably considers the proposed groups as comparable and of equal rank and value. From the American standpoint the proposed groups cannot be considered comparable or of equal rank. They cannot constitute, therefore, the groups of a single category, complete or incomplete. The American objection is based on the totally different causes which have operated in the production of the characteristics on which the grouping is based. The first three groups are true, fully developed soil types permanent under existing environmental conditions and wholly the product of that environment. The others are the product of internal conditions, have no relation or only an accidental relation to the exterior environment, and are not permanent. They will inevitably change without a change of the environment in which they lie and as the product of the normal progressive development of that environment. They are local, the others are general.

Up to the close of the Rome Conference, no comprehensive scheme of soil classification had been presented to the commission nor had any agreement been reached by its members regarding the bases on which the categories as a whole, or each category in detail, should be based. A number of schemes consisting of one category, or at most two categories, had been submitted, but they can be considered only as definitions of certain soil groups and not as schemes for the classification of all soils either on the basis of all their fundamental characteristics or on that of the several forces and conditions constituting the causes of soil development.

The commission on soil cartography presented a report to the conference at Rome describing the work in soil mapping in the various countries of Europe, some of the Asiatic and African countries, and the United States. No soil maps were presented, with the exception of a small generalized map of Roumania and another of Hungary.

The commission on soil classification and that on soil cartography were combined at the Rome Conference into one commission to be known as the Fifth Commission, on the Classification, Nomenclature, and Mapping of Soils, with two subcommissions, one on the cartography of soils in Europe, and the other on the cartography of soils in the Americas. C. F. Marbut of Washington was named president of the commission and Hermann Stremme of Danzig the president of the European subcommission on the soil mapping, Marbut retaining the presidency of the subcommission on the soil mapping of the Americas.

On a motion by Aarnio, the members of the commission resolved to devote themselves, during the three years which would elapse before the meeting in Washington in 1927, to the study of soil profiles in their respective countries in order to accumulate enough data, on the basis of which a comprehensive scheme of classification could possibly be based.

The commission on cartography resolved also to present to the next Congress in Washington generalized soil maps of as many countries as possible, and,

if possible, generalized soil maps of Europe and the Americas. The work of the new commission had thus been rather definitely laid out. It had not been suggested that the various members construct proposed schemes of soil classification for consideration by the commission in Washington, but their work was to consist of an accumulation of soil data on the basis of which a scheme might be constructed. The submission of schemes, however, was not prohibited.

In addition to the principal work of the Commission, it seemed desirable, by way of clearing the ground, to discuss at the Washington meeting and to determine through such discussion the value of certain groups of data heretofore used as bases of soil grouping. The first part of the program of the Commission was devoted therefore to the discussion of these data under the following titles:

1. Should the various categories in a scheme of soil classification be based on soil characteristics or on the forces and conditions which have produced them?

2. What is the comparative weight to be given field and laboratory data in a comprehensive scheme of soil classification?

3. To what extent should location, topography, or physiography constitute a basis for the differentiation of soil into units or groups of units?

4. To what extent may the geological characteristics of the parent geological material be used as a basis for the definition of soil units and their classification?

5. To what extent should the climate of a region be used as a basis for the establishment of the groups in a scheme of soil classification.

These subjects were assigned to various specialists in the United States and Europe, being selected on the basis of familiarity with the particular subject.

The discussion following the reading of the papers was very lively, the first and fourth subjects attracting the most attention. The interest taken in these papers indicates that a practical unanimity of opinion prevails as to the bases on which soil classification should stand and that the old geological basis should be abandoned as that of any of the two or three higher categories in a comprehensive scheme, but cannot be discarded entirely, it being necessary to give it recognition in one of the lower categories. In general it became clear that although widely different opinions prevailed, they concerned details rather than general principles. It became evident that each individual looked upon classification from the standpoint of his own experience. This is but the inevitable consequence of the nature of the subject and the present status of the science. The specialist working on some one of the many phases of soil investigation pursued in the laboratory may be able to become acquainted with all the lines of such investigation, but soil classification must necessarily be based on a knowledge of soils as they exist in nature and this cannot be determined by means of laboratory material. Soils must be seen in their natural habitat and this requires travel, time, and resources. Very few soil specialists have yet had the opportunity of studying all the soils of the world.

Each specialist discussed the matter from the viewpoint of the conditions

prevailing in his own country, but each likewise manifested a keen interest in and sympathetic understanding of the viewpoints of persons whose experiences had been different from his own. It became evident, therefore, as the discussion proceeded, that although the basis used by the specialist from each country may be of very limited range it is, however, fundamental and may well constitute the basis of one or two categories in a comprehensive scheme.

The papers presented by the specialists who were invited to discuss the four subjects mentioned above will be published in the Proceedings of the Congress. No full discussion is necessary here. The first one presented by T. D. Rice of the Bureau of Soils showed the necessity, in a scientific classification of soils, of basing the categories on soil characteristics entirely. His conclusions were discussed by colleagues from most, if not all, the countries represented in the meeting, and practically universal agreement was voiced.

To the devotees of the other sciences it may seem somewhat strange that such a subject should receive serious treatment in a meeting of specialists. To the soil specialist, however, who is familiar with the former geological basis for soil classification, its discussion is necessary. The geological basis is still the prevailing one in American text books and in most American teaching. The soil specialist knows that such a classification has no relationship whatever to soil characteristics and that it differs fundamentally in this respect from the so-called climatic basis of classification. It is now clearly recognized that the so-called climatic groups are in fact character groups and that the classification, as far as it goes, is in reality based on characteristics, and that the nomenclature only is climatic. The groups on the other hand, in the geological classification are not groups with common soil characteristics. They are geological groups entirely and not soil groups.

A classification on a climatic basis is not satisfactory, however, even though the groups of such a scheme as the Russian, have real characteristics in common. Such a basis is inadequate because it is not adaptable to all the categories necessary in a complete scheme. Many fundamentally important soil characteristics cannot be ascribed directly or even indirectly to climatic influence and such characteristics must be given recognition in a complete scheme.

The second general subject was treated by G. W. Robinson of Bangor, North Wales. He brought out clearly the fact that soil classification, being concerned with soils as natural bodies must stand primarily on the basis of their tangible field characteristics. The rôle of laboratory data in such work is two-fold. It must be resorted to in many cases when an *explanation* of field phenomena is sought and again it may be resorted to in obtaining data which cannot be obtained readily, or possibly at all, by field methods. Its importance, therefore, is subordinate to that of field data, but in the work of determining the processes through which field characteristics have been developed it is indispensable.

The third subject was treated by T. M. Bushnell of Purdue University.

He showed clearly that neither topography, location, or physiography can be used as a basis for soil classification as a whole or as the basis for any category. He showed that soil characteristics, however, have a very intimate relation to topography and physiography. Neither constitutes a soil making force, but merely modifies the intensity of the action of a given force or prevents its operation entirely, but such passive limitation may or may not take place. As in other cases, he brought out the principle that, in this case also, the only rational and sound basis for the classification lies in the characteristics themselves. The causes of those characteristics are not necessarily concerned with classification. It should be stated here, that a classification according to characteristics must necessarily show the relationship of the units and groups of such a scheme to the forces and conditions prevailing on the surface of the earth or to the physical environment in which soils are developing or have developed. It is only through the characteristics, however, that a knowledge of the forces producing them is obtained. This relationship and a nomenclature recognizing it often cause us to describe a soil group as a climatic group or some other causal group, when, in fact, the grouping is based entirely on characteristics and the nomenclature only refers to causes.

The fourth of the general subjects was presented by Otto Veatch of the Michigan College of Agriculture. He brought out clearly the total lack of correspondence between the broad characteristics of the soil and the geological formations from which they have developed. In his paper he confined himself to the discussion of this lack of agreement insofar as it concerned the broad characteristics of the soil. In the discussion, J. Hendrick of the University of Aberdeen, Scotland, showed how very closely the characteristics of the soils of northeastern Scotland coincide with and change with the characteristics of the geological formations from which they have been derived. It was brought out in the discussion, however, that the points of view both of Veatch and Hendrick are right. Veatch was discussing the characteristics of soils such as prevail over continental areas and showed that so far as these characteristics are concerned there is no relationship whatever to the rocks from which the material was derived. He showed also that these characteristics are fundamental soil characteristics and that they cannot be neglected in any scheme of classification and that an attempt to account for them on the basis of geology is entirely futile.

Hendrick was discussing the soils of a small region in which the broad characteristics to which Veatch was referring did not change and all the change in characteristics with which Hendrick was dealing were included within a single one of the groups Veatch was discussing. It was also brought out that in every region there are fully developed, or *mature* soils, and imperfectly developed soils, and that within such a region there may be large areas in which *all* the soils are incompletely or imperfectly developed. Such soils usually show a close relationship to the parent rock. It was brought out that a complete scheme of soil classification must provide categories into which soils with fully developed

characteristics free from any relation to the parent rock and also imperfectly developed soils can both be fitted. It was brought out that some soils still inherit their main characteristics from the rock, whereas others have lost them entirely. Both kinds must be taken care of in a complete scheme of soil classification.

The fifth topic was discussed mainly by Glinka and other members of the Russian delegation. The Russian point of view, long since accepted in its essential outlines by the pedologists of the world, was well presented. Some objection as to details and nomenclature was voiced mainly by American workers. It was pointed out clearly however that although the development of the facts on which the Russian classification is based refers to the climate, the groups in the scheme are based on soil characteristics and not on climate. While the results of the Russian work are now universally accepted as far as they go, this latter being determined by the relatively limited range of environmental conditions in Russia, it is now universally agreed that their scheme will have to be widened in its range. This matter is discussed in the paper on "The American Point of View" in this number (p. 61).

In addition to the papers discussing the fundamental bases of classification, 40 papers dealt mainly with detailed soil profile characteristics in various regions or countries. One of the most thoroughly worked out papers in this group was one by Bjorlykke describing and illustrating in great detail by a series of colored charts, the soil profiles of Norway.

These papers cannot be discussed in detail here. Suffice it to say that they constitute a store of soil profile data which will be found useful finally in constructing a scheme of soil classification world wide in its scope.

Two proposed schemes for soil classification were presented for consideration but neither was discussed as a whole. C. F. Shaw presented one of them and C. F. Marbut the other, the latter being presented to the subcommission on alkali and salty soils merely for the purpose of showing the relationship of these soils to normal soils developed to full maturity free from inhibiting conditions of any kind.

The subcommissions on the international soil maps of Europe and the Americas presented reports. The former submitted the first soil map of Europe ever constructed from the modern point of view. It is unnecessary to describe it in detail here, but it must be regarded as an important expression of progress in soil science for representative soil specialists from many countries to agree that the classification of soils on the basis of their characteristics is the only fundamentally sound basis for such work. It is an important conclusion not merely because it is thoroughly scientific but because it will promote the development of the science through making necessary the accumulation of knowledge concerning soil characteristics.

The subcommission of the Americas presented a soil map of the United States; one of Cuba by H. H. Bennett of the U. S. Bureau of Soils; and maps

of Alberta and Saskatchewan, by Wyatt of the University of Edmonton and Joel of the University of Saskatoon. No map of Portuguese or Spanish America has yet been constructed, and the data available do not render it possible. A very generalized sketch of soils in Chili was presented by Matthei, delegate from Chile.

SUBCOMMISSION II

CLASSIFICATION, NOMENCLATURE, AND MAPPING OF SOILS IN THE UNITED STATES

THE AMERICAN POINT OF VIEW

C. F. MARBUT

President

(U S Department of Agriculture, Bureau of Chemistry and Soils)

Two continents, the Eurasian and the North American have been studied in sufficient detail to warrant the formulation of generalizations regarding their soils. This statement applies somewhat more specifically to the eastern part of Europe and the western part of Asia on the one hand, and to that part of the North American continent included within the boundaries of the United States on the other, but enough is known of the rest of Europe and a considerable part of the rest of North America to warrant the statement that little change other than by addition, will be made to the generalizations now possible, when they become better known.

The facts accumulated from the two continents by soil investigators have demonstrated clearly that the general characteristics of the soils in both of them run parallel in geographic distribution, with the distribution of the general features of the climate. This generalization has now been accepted by the specialists of both continents and they are agreed also that this geographic relationship is one of cause and effect rather than merely accidental. It is now accepted by well informed pedologists in both continents that a number of highly important general characteristics of soils have been produced by climatic forces.

This relationship was first worked out in Russia and to the pedologists of that country must be given the credit for establishing and formulating the fundamental principles of the science of the soil. The conditions exist in the North American continent which would have made possible the development of these principles on the basis of American facts, but field studies did not begin in this country until after they had been worked out in Russia. To an American pedologist, E. W. Hilgard, is due however, the credit of first calling attention to the differences between soils developed under humid conditions and those developed under arid conditions. He saw the significance of climatic influence in soil development, and, had circumstances made it possible for him to study the soils of the United States, he would have been able to work out the principles of the science on the basis of American conditions.

The climatic conditions, however, are more complex in the United States

than in eastern and southeastern Europe and western Asia. Whereas the general characteristics of soils, those having wide distribution, are known to have been developed by climatic forces, other characteristics less general in their nature and less widely distributed are due to other factors than climate. It is apparent that these factors also are more complex in the United States than in Russia. All the forces and conditions to whose influence soil characteristics are due seem to be more complex on the North American continent, therefore, than in the Eurasian continent. This is due in part to inherent complexity and in part to the great size of the area covered, in which is included a wider range of those influences controling the development of organisms on the earth's surface, of which the soil is one, than are included in southeastern Europe and western Asia.

It is apparent therefore, that the working out of the relationships of soils to the environment was more easily done in the Eurasian region than in North America. It is apparent also that had these relationships been worked out in North America they would have been from the beginning more broadly applicable than those developed from Eurasian conditions. It must be borne in mind in this connection that this statement refers to the range of application of the fundamental principles involved and not to the principle itself, the principle of the relationship of soil character to the environment, especially the climate being as firmly established by the simpler Eurasian conditions as could have been the case had it been established on the more complex conditions in North America. Indeed it is very probable that, because of these simple conditions, the relationship was more clearly seen than would have been the case in North America.

The Russian pedologists were able to formulate the general principles of soil genesis. On the basis of the soil characteristics prevailing over wide areas of country they were able to define a number of soil groups, in each of which a given series of characteristics prevails. Because of the relative simplicity of conditions, the number of these is not large.

The wide range of climatic change within the United States and the greater complexity of climatic conditions, or the greater number of well defined combinations of climatic factors makes it evident that the conditions favoring a wider range of soil characteristics in this country than in European and Asiatic Russia are well defined.

For example, the range of annual temperature in Russia, within the region in which the rainfall is approximately uniform seems to be not more than 5° F. In the United States the range within a similar belt is not less than 35° F. In Russia the lines of equal temperature change run parallel with those of rainfall change but as the temperature increases the rainfall decreases. In the humid part of the United States the lines of temperature and rainfall change run approximately parallel also, but both temperature and rainfall increase in the same direction toward the south. In this part of the United States the two climatic factors of primary importance increase together, in Russia, however, as one increases the other decreases.

The change in amount of rainfall southward in the humid eastern part of the United States is not, however, the direction in which the most important change in rainfall takes place in the United States. The change from east to west is much greater and much more significant as a factor in determining changes in the character of the soils than that from north to south. This change however, does not take place in a direction parallel to that in which changes of temperature take place, as in the eastern part of the United States but approximately at right angles to the latter. Changes in rainfall take place from east to west, of temperature, from north to south. These directions of change of the two important factors in soil evolution therefore run approximately perpendicular.

In Russia, on the other hand, these directions run approximately parallel in the region of low rainfall as well as in that of high rainfall, so that a given environmental condition produced by a given rainfall and given temperature occupies a narrow belt, strictly a line, running approximately east and west, whereas in the United States a similar condition will occupy a spot. In the former country an environmental condition produced by a given narrow range in rainfall and in temperature will occupy an east-west belt; in the latter it will occupy a quadrilateral area. It is manifest that within any given area or belt with a given range of temperature and rainfall change, the number of climatic variations produced by combinations of different degrees of temperature and different amounts of rainfall will be much greater in North America than in eastern Europe and adjacent western Asia.

If climatic differences produce soil differences, and that they do so has been fully demonstrated by Russian work, it is evident that the range in soil characteristics in the United States, even if we leave the rest of the continent out of consideration, must be much greater than those in eastern Europe and western Asia.

Where the range of climatic differences is as wide as in the United States the soil differences must be equally wide. Whether these differences in soils be enough greater than those in Eurasia to produce a number of new *soil types* depends of course on the amount of elasticity allowed in the definition of a soil type. The existing American point of view maintains that the differences are sufficiently large to make this inevitable. The American point of view accepts the results of the work of the Russian pedologists in soil genesis and accepts the great soil groups, or as the Russian colleagues call them *soil types*, defined by them, but maintains that the more complex conditions existing in this country have created a number of additional groups worthy of being granted the rank of *soil types* in the Russian sense. At present, American pedologists consider it impossible to crowd all the American soil groups into the scheme created to fit Russian conditions.

The conditions on the North American continent seem to be about as complex as those on any of the continents and it becomes apparent, therefore, that a definition of all American groups and the construction of a scheme of classification into which they can be fitted will be broad enough to include most of the

soils of the world. It is probable that the American soil groups will cover all the temperate and subtropical regions of the world.

Of the soil groups, considered by American investigators to possess characteristics sufficiently distinct to warrant their recognition as independent types, but which are not equivalent to any of the Russian groups, the soils occupying the mid-latitudes of the eastern part of the United States stretching from the Atlantic to western Indiana and from central New York and New England to the Chesapeake Bay and the Ohio River constitute one. They have been considered for several years as the equivalent of the *Braune Boden* of Ramann but the descriptions of that group, including the chemical analyses published by Aarnio and by Aarnio and Stremme, show that in northern Europe the profiles are much less perfectly developed than in the United States. Stremme's descriptions of Braunerde from Hungary and Roumania on the other hand indicate the presence in southern Europe of soils more like those in the United States. Russian pedologists have not granted full recognition to the Braunerde of Ramann as a soil type comparable to the Podsol type, but treat it as a phase of the Podsols. It is undoubtedly a podsolic soil but so also are the Roterden and Laterites.[1] If we recognize Laterite as a type comparable to Podsol, there seems to be no reason why Braunerde and Roterde should not be given the same status. Although the relationship of the area occupied by Braunerden to the sea lends some suggestion to the claim sometimes made that they are merely a phase of the Podsols developed under the influence of a maritime climate, in the United States the members of the group stretch from the seacoast inland for nearly a thousand miles without any fundamental change in their general characteristics. In the United States, these soils, whether or not they are identical with the Braunerden, are characterized by features wholly unlike those of the Podsols and they have developed also under the influence of different climate and a different vegetation from those prevailing in the Podsol region. Because of this difference both in characteristics and in the climatic and biological conditions under which this soil group and those of the Podsol group have developed, the American pedologists cannot refuse to give them equal rank.

[1] The basis for this statement cannot be presented here. A discussion of the matter including the presentation of the available data is in preparation and will be published in a short time.

Hydrated iron oxide accumulates in the normal B horizon of the soils of each of the groups mentioned apparently by the same processes as those causing its accumulation in the Braunerden and the Podsols. If the accumulation in the B horizon of the Braunerden has been brought about through the operation of the podsolizing processes, it is very difficult to explain the accumulation of the same or similar material in the Roterden and Laterites by a different process.

The accumulation of the hydrated iron oxide and its segregation into a solidified layer in Laterite is brought about by an entirely different process and does not take place in the normal B horizon.

South of the belt of Jerseyan[2] soils running parallel with the latter lies a belt of soils in which the dominant color of the B horizon is red rather than brown as in the Jerseyan group. They are podsolic, if by that term we designate soils in which sesquioxides and bases have been removed from the A horizon and the former at least accumulated in the B horizon. With the podsolization has gone a more intensive removal of alkalies and alkaline earths and apparently of silica than takes place in the Jerseyan or the true Podsol soils. All these processes are operating according to Horassowitz[3] and many others in the soils of both the latter groups. In the red soils they have operated and are now operating more intensively than in the other soils.

Although the red soils, which will be designated the Georgian soils in this paper, merely for convenience, do not differ in fundamental characteristics from those of the Jerseyan group, they differ greatly in the degree or intensity of development of those characteristics. They are both the product of the same forces apparently, but of widely different degrees of intensity in the operation of those forces.

The soils of both groups are humid but the Georgian soils were developed under the influence of a much higher annual temperature and under a somewhat higher rainfall than the Jerseyan. The climatic difference is due mainly to difference in temperature but if we are justified in differentiating groups on the basis of characteristics due admittedly to differences in amount of rainfall, and if we admit as we may assume has been done, that temperature as well as rainfall is a factor in soil development, it seems logical to differentiate groups on the basis of characteristics due to differences in temperature also. In doing this we may neglect the question as to whether changes in temperature are effective in soil evolution *per se* or only through their influence on the effectiveness of the action of moisture. This question of the justification for differentiating soils into comparable groups on the basis of characteristics due to changes in temperature where rainfall remains constant does not arise in the treatment of the soils of eastern Europe since the two kinds of changes run parallel. The American pedologists, in the present status of knowledge concerning the soils of the United States, maintain that if it is justifiable to differentiate the soils of the United States into groups, along a given isothermal line, from east to west on the basis of characteristics due to changes in rainfall, it is equally justifiable to group them into comparable groups from north to south along lines of approximately equal rainfall. They maintain an open mind regarding the matter, however, and will change their attitude if and when the facts show the untenability of their existing position.

These soils seem to include the Terra Rossas of Mediterranean Europe and Asia but the latter have not yet been granted the rank of an independent group of soils comparable with the Podsols. In the Caucasus they have been

[2]This term is used merely for convenience in this paper to designate the soils of the group being discussed.

[3]Laterites—Borntraeger Bros. (1926), Berlin.

interpreted as the product of weathering during tertiary times. It is possible that some of the Red soils of the United States are the product of Tertiary weathering, but no evidence has yet been accumulated showing that the same kind of weathering is not now in progress and has not been in progress continuously from the time the oldest Red soils were produced, when ever that may have taken place.

South of the belt of Red soils, occupying the southeastern part of the United States, lies a region in which prevail soils having some characteristics different from those of any of the groups already described. The most striking of these characteristics prevail thence southward throughout the tropics and have been considered characteristic of tropical soils. The most striking characteristic and the one now considered worthy of serving as the basis of a separation of the group from those already described, prevails almost everywhere in Cuba, in tropical South America, Africa, and parts of southern Asia. This consists of the presence either in the lower part of the B horizon or the upper part of the C horizon of segregated iron hydroxide either in the form of concretions or of a consolidated porous vesicular mass. The thickness of the horizon varies considerably as well as the degree of concentration and induration. In the United States the iron oxide occurs in the form of concretions only.

The characteristics of the rest of the profile are, as far as existing knowledge goes, not fundamentally different in *kind* from those of the Georgian or Jerseyan but seemingly only in the degree of leaching that has taken place, both of bases as well as of silica. At present the basis of differentiating them from the Georgian and Jerseyan soils consists of the accumulation and segregation of the iron hydroxide. Whether further investigation will show that this basis is not sufficient for the purpose is not now known. It is known that facts are now in existence which tend to show that the soils with this concentration and segregation of iron hydroxide are not fully comparable with the groups already described and even of other soils known to occur in the tropics. For the present, however, the group definition stands on that basis.

The A horizon is podsolized seemingly to the same or to a similar degree as in the other groups described. The B horizon above the zone of iron oxide segregation, is normally developed as a well defined illuvial horizon with normal concentration of iron oxide and alumina though it is not universally red in color.

Climatic forces do not constitute all the forces of the environment in which soils develop and which perform important functions in the determination of their characteristics. The characteristics of Posdol soils, on the basis of which they are differentiated from other members of the great group of soils developed under forest cover, are due to some extent to the kind of forest trees prevailing in the area occupied by each group.

If the kind of forest trees has an important influence on the characteristics of the soils developed under them we would seem to be justified in concluding that differences in natural vegetation greater than those of different kinds of

trees, such as the differences between grass and forest, would have at least an equal effect on the soils developed under them. In that part of the United States in which the rainfall is sufficient to have removed all easily soluble salts as well as all carbonates from the solum, by the time the latter has become well developed there is a large area underlain by soils developed under grass vegetation. They occupy a region lying west of Indiana, in the greater part of which the annual rainfall and temperature are essentially like those in the forested regions to the east. The climate varies from palce to place but it is everywhere humid except along the western boundary where it gradually becomes sub-humid.

The soils range from dark brown to black, dark brown being the color of the dominant fully developed soil. Over large areas they have been derived from highly calcareous parent rocks but the normally and fully developed soils throughout the region contain no carbonates in the solum. The structure of the well developed soils is highly granular, differing in this respect from the soils of the Jerseyan and other groups already described, but the lamination characteristic of the A horizon of the Jerseyan soils is often present also. On the basis of these characteristics the American pedologists feel justified in placing them in a distinct group comparable with the groups already described.

In existing European literature, these soils occupying the prairies of the United States are usually described as "Wiesenböden" or wet land soils, or as "degraded Tschernosem." Although there are areas of wet land soils, within the *prairies*, as this region is designated, they do not constitute the normal soils of the region. The soils of the greater part of the region have developed under conditions of complete freedom from the influence of excessive moisture and in this respect they do not differ from the predominant well developed soils of the forested regions of Indiana, Ohio, Michigan, Wisconsin, or Minnesota.

American pedologists have not yet accumulated any facts indicating that the soils which the author designates as *Prairie soils*, are degraded Tschernosem. That they have been podsolized to a slight extent is well known. The structure particles in some parts of the region where the soils are normally well developed are coated with a thin "pepper and salt" coat, often a mere sprinkling of gray and in other cases nearly white. Their characteristics, however, do not coincide with those of degraded Tschernosem as that soil is described in European literature. That such soils are degraded Prairie soils seems more probable. All the carefully drawn descriptions mention a well defined zone of carbonate accumulation in degraded Tschernosem. Reasoning from the *a priori* standpoint indicates that since degradation is brought about through the action of increased moisture, the first effect of the process would be the podsolization of the surface horizon and the removal of the organic matter, since the organic matter lies near the surface. Although seemingly no studies have been made directly on the point, it is highly probable that the dark color of the Tschernosem will have disappeared long before the carbonate in the zone of accumulation will have been noticeably affected. In the vicinity of Bucarest,

Roumania, this is undoubtedly the case. The dark color has entirely disappeared, yet the carbonate horizon is still well defined. If this be the course taken by the changes, it would be expected that, since the prairie soils are still dark in color, and presumably, if they be degraded Tschernosem, the zone of carbonate accumulation would still be found intact. As everyone who has studied them knows, there is no such horizon present, and no evidence that any ever existed has yet been reported.

The interpretation of the Prairie soils as degraded Tschernosems demands more than one important change of condition. Up to the present time degradation has been ascribed to a change of climate from dry to wet, accompanied by an invasion of the former dry grass-land soil by forest. It is apparent that the result has never been ascribed to any other course of events. If, therefore, our Prairie soils be degraded Tschernosem, the region must have been one, until a relatively short time ago, with low rainfall. For the prairies of Illinois, Iowa, and Missouri, it must have been less than 20 inches. The rainfall in the region became greater, forests invaded it, and in the course of time the soils became ordinary forest soils. In order to bring them into their existing condition the forest must have disappeared. If it disappeared through a change of climate from wet to dry, the soils must have developed once more the characteristics of Tschernosems. A second change from dry to wet must have taken place in order to bring conditions to where they are today. This, however, does not assist us in the least in accounting for the disappearance of the lime zone before dark color of the surface soil has disappeared. That difficulty is exactly the same as is found in assuming that the change take place directly with one change of climate. Whether by one change of climate or by three, the real problem is to cause the disappearance of the lime zone almost before the degradation of the dark colored horizon, the only horizon in which the operation of degradation has as yet been noted, has attained more than a mere beginning.

The other difficulty is the fact that so far there is no evidence whatever that even one change of climate has taken place in that region in recent geological time. As the matter stands at present and until more evidence has been accumulated, the American pedologists, while maintaining an open mind with regard to the matter, must place the Prairie soils in an independent group comparable to the Posdols.

Westward across the prairies the rainfall decreases gradually until finally a point is reached on any latitude within the United States and apparently of Canada, west of which, except in the mountains or on or near the Pacific Coast, it does not suffice to maintain a dominent downward percolation of water and in which the soil is only rarely saturated with moisture to a greater depth than a few feet. In such condition the carbonates, especially lime carbonate developed by the carbonation of the calcium, released through the decomposition of the silicates, accumulates on some horizon of the soil profile. A line connecting these points, which will run for northwestern Minnesota to the vicinity of Corpus Christi, Texas, will divide, from the American point of view,

the soils of the United States, except those in the Western Mountains, into two groups; namely, a group in which lime carbonate accumulates during the course of soil development and because of the forces operating in the soil on some horizon of the soil profile, and a group in which no such accumulation takes place regardless of the character or composition of the parent rocks. (Soils developed from rocks made up of absolutely pure quartz, if there be such, are not included in this grouping.)

The soils lying immediately west of this line in a north-south belt varying in width from a very few miles to perhaps a hundred are designated by American pedologists as the soils of *The Tschernosem Belt*. In this belt the annual temperture ranges from 23° F. with a July average of 59 and a January average of −23 in Alaska to an annual temperature of 36° at Edmonton, Canada; 35° at Winnipeg, Canada; 49° at North Platte, Nebraska; 64° at Abilene, Texas; and 70° at Corpus Christi, Texas. The July and January averages in these same localities, including again Alaska, are 59 and −23; 61 and 5; 66 and −4; 74 and 23; 82 and 44; 82 and 56, respectively. The annual precipitation at these places is 15, 18, 20, 19, 24, and 25 inches, respectively. North Platte lies a little further west, in this belt, than the other points mentioned so that its rainfall is lower than would have been the amount had the data for a point in this latitude, lying in the eastern part of the Tschernosem Belt been available. All the other points lie near the eastern boundary of the belt.

On the basis of the extremely meagre data available at the moment it seems that the rainfall within the Eurasian belt designated as Tschernosem by Russian pedologists ranges between 20 and 25 inches, a range less than that in the American continent. The most significant difference, however, lies in the range of temperature in the European belt. The lowest annual temperature in the entire belt seems to be 32° F. and the highest 36°. In North America the range if from 36 to 70°. In the Tschernosem belt of Europe and Asia, the differences in rainfall and temperature from east to west along lines maintaining the same distances throughout their course from the northern and southern boundaries of the belt are very slight. In the North American continent differences in both are important, but those of temperature are very large.

It requires no argument to convince the pedologist, knowing the influence of differences of temperature on soil characteristics, that the soils throughout the entire *Tschernosem Belt* in North America cannot be uniform. Although in some respects the soils of this belt are like the true Tschernosems, it is evident that they cannot all be classified with the typical soil. In the presence of a zone of carbonate accumulation, in their high percentage of saturated organic matter and dark color and in the well developed granulation, the soils are like the Tschernosems. In color they vary greatly from north to south. In that respect they are not uniform, but the soils of any given latitude of this belt are darker in color than any other soils in the same latitude in which a zone of carbonate accumulation is present. The true Tschernosems in this belt can have developed only in that part where the annual rainfall and the

annual temperature are the same as in the Tschernosem belt of Eurasia. This lies in the northern part of the United States. In Canada it is apparent that the annual temperature is lower than in the Eurasian Tschernosem belt, the winters are longer, the summers are shorter, and evaporation is lower. The rainfall is not higher, however, so the lower evaporation would have little effect on the depth to which carbonates have been removed. The main effect is that arising from a higher percentage of moisture in the surface horizons of the soil than in the true Tschernosem, resulting in the accumulation of a higher percentage of organic matter, through a more luxuriant growth of grass. South of the stretch in which the soil is essentially equivalent to the Eurasian Tschernosem the opposite effect is produced, so that the less luxuriant growth of grass stores a lower percentage of organic matter in the surface horizons. They are therefore lighter in color. The higher temperature and the more intensive oxidation resulting from it give the surface soil a brownish shade and the lower horizons, especially one lying above the zone of carbonate accumulation and below that of high organic matter, become red or reddish. The carbonate zone is often reddish also but less so than the horizon immediately above it.

The chemical expression of these color differences has not yet been determined. These soils have been studied but very little. It is known, however, that the carbonate concentration is much greater than in the northern part of the zone, becoming so highly concentrated in the southern part of the belt as to develop an induration equal to that of limestone.

It is apparent that the varying characteristics in the *Tschernosem Belt* of North America warrant a subdivision of the soils of the whole belt into at least 3 and probably 4 subgroups. One of these will include those soils in the northern part of the belt extending from northern Canada into North Dakota. A second group will include those soils of the belt extending from North Dakota to southern Kansas. These seem to have characteristics similar to if not essentially identical with those of the Eurasian Tschernosem. A third group will include those soils of the belt extending from southern Kansas to Central Texas. The fourth group, if it exist, will include the soils with an indurated and concentrated carbonate zone in southern Texas.

The belts of *Chestnut colored, Brown and Gray soils* lying, in the order named, west of the *Tschernosem Belt*, may be subdivided into northern, central, and southern stretches also but they need no description here.

FIFTH AND SIXTH COMMISSIONS

Fig. 1. J. Girsberger, Switzerland, President of the Sixth Commission (Copyright Harris & Ewing). Fig. 2. A. P. Dachnowski-Stokes, U. S. Department of Agriculture, Chairman of the Peat Subcommission of the Sixth Commission. Fig. 3. C. F. Marbut, U. S. Department of Agriculture, President of the Fifth Commission, and Organizer of the Transcontinental excursion (Copyright Clinedinst Studio). Fig. 4. H. Stremme, Germany, Chairman of the Third Subcommission of the Fifth Commission (Copyright Harris & Ewing). Fig. 5. F. R. Weis, Denmark, Chairman of the Subcommission on Forest Soils of the Fifth Commission. Fig. 6. R. Zon, U. S. A., active in the organization of the Subcommission on Forest Soils of the Fifth Commission.

SUBCOMMISSION III

THE INTERNATIONAL SOIL MAP OF EUROPE[1]

H. STREMME

President

(Technical High School, Germany)

At the Fourth International Soil Conference at Rome in 1924, the two commissions on the nomenclature and classification and on cartography agreed to prepare a general soil map for use at the First Soil Congress at Washington in 1927. It was possible to send this map, with a short explanation, to all members of the International Society of Soil Science just before the Congress in May, 1927, thanks to the collaboration of more than 30 European soil scientists: V. Agafonoff, France; J. van Baren, Holland; K. Bjorlykke, Norway; G. Boutschew, Bulgaria; N. Comber, A. Fraser, J. Hendrick, G. Newland, W. Ogg, and G. Robinson, Great Britain; T. Enculescu, G. Murgoci, and E. Protopopescu, Roumania; B. Frosterus, Finland; G. Georgalas, Greece; K. Glinka, Russia; J. Halissy, Ireland; K. Heykes, V. Hohenstein, W. Hollstein, G. Krauss, F. Münichsdorfor, H. Stremme, and W. Wolff, Germany; H. Jenny and G. Weigner, Switzerland; T. Mieszynski and S. Miklaszewski, Poland; V. Novak, Czechoslovakia; A Oppermann, Denmark; B. Ramsauer and A. Till, Austria; A. Stebutt, Jugoslavia; O. Tamm, Sweden; P. Treitz, Hungary; E. del Villar, Spain; and J. Wityn, Latvia. The map was prepared in Danzig at the Institute of Mineralogy and Geology of the Technical University of the Free City.

The mapping was done according to the morphological method of the Russian soil scientists. They consider and compare the natural soil horizons in the soil profile and classify the soils or the types of soil origin into several large groups, of which the most important are the "Tschernosem" or steppe soil and the "Podsol" or forest soil. The steppe soils have some dark humus horizons and if calcareous a horizon of lime carbonate. The forest soils have dark and light humus horizons with enriched quartz, below which are some horizons with precipitated clay substances and sesquioxydes of iron, aluminum and manganese.

These two characteristic groups of soils are climatic types, or types of the great climatic vegetations. Climate and organisms are the factors which determine their various soil horizons. Other factors that influence the soil

[1] The map and the explanation are published as a paper of the Prussian Geological Survey at Berlin.

formation are the relief, the soil and ground water, the parent rock, and the human labor.

The relief has a great influence on the evolution of the soil horizons. In the flat relief we find the best development of the "climatic" types, Tschernosem and Podsol. In the middle relief the upper horizons wash away and leave ruins of soils. The masses which are washed down accumulate in the low grounds. In the sharp relief the parent rock becomes uncovered; only pebbles of the parent rock remain of the soil formation. They are called skeleton soils or soil skeletons.

Standing soil water modifies the soil horizons. In the surface soil the humus substances take on another characteristic of the nature of peat formation, in the subsoil, ferric, calcareous, clay, saline matters, sulfides, or ferric phosphates are precipitated. Standing or running water forms the soils of the river valleys and of the coastal swamps.

The parent rock resists all the processes of soil formation, some rocks more than others. The heaviest resistance against the several factors of the soil formation occurs in the limestones, dolomites, and gypsum. On these rocks only a shallow soil profile may be formed, which is sooner removed than a deep profile.

The human labor of agriculture and forestry has some influence on the formation of the soil horizons in all cases in which they are not deep or the relief is moderate or strong.

The distribution of the several soil types is shown on the soil map of Europe (the soils of the desert steppe (Wüstensteppe), steppe, antesteppe, and forest steppe). The forests have their best development in the large flatlands of Russia, whence one branch goes through North Germany, Holland, Belgium, and France as far as the Pyrenean Mountains and another branch goes through Roumania as far as Bulgaria. Middle Europe with its mountainous countries shows only small regions of the climatic types, surrounded by others and by skeleton soils of the high mountains. The peninsulas of Southern Europe are also mountaineous. They have small regions of the climatic types. In Spain a dry forest soil shows the dry character of this country, in which the cutting down of the forest has a greater influence than in the humid region. Great Britain has skeleton soils in the higher mountains surrounded by forest soils with a strong development of the light-colored humus horizons and the red or yellow brown subsoil. In the flat southeastern parts the forest soils have humus substances in the brown subsoil (braune Waldböden) and are not so thoroughly leached as the more "podsolized" soils of the more humid regions.

SUBCOMMISSION V

THE STUDY OF FOREST SOILS

FR. WEIS

Chairman

(Royal Agricultural College, Denmark)

When, during the First International Congress of Soil Science held in Washington in June, 1927, a special subcommission (under the Fifth Commission) for the study of forest soils was appointed, with its own meetings and the probability of maintaining a separate existence in the future, it was because the executive committee of the Conference appreciated to the full the importance of this branch of the subject.

The remarks which follow on the special problems which the study of forest soils presents and of the lines of work to be followed are somewhat subjective in their point of view, drawn from personal experience and the scientific literature on the subject available at present, and on this account the conclusions are largely based on the problems which are of importance in cold (and temperate) humid regions as shown in the investigations made in Northern and Central Europe. The author is moreover, personally responsible for the views presented here. Although dealing with a larger number of details, these ideas do not conflict with the report of the vice-president of the subcommission, the director of the U. S. Forest Experiment Station at St. Paul, Minn., Zon, (collaborating with Kittredge) under the title, "The Most Important Forest Soil Problems From the Standpoint of the Foresters of the United States."

Whereas that branch of soil science which is concerned with cultivated field and garden soil, deals, in the main, with a soil which has been largely changed by human intervention--by mechanical treatment, drainage or irrigation, fertilization, the cultivation of domestic plants and the extermination of the original vegetation (weeds)—in forest soils we are dealing primarily with a virgin soil, as formed by nature. As all tilled soil, however, was virgin soil originally (forest, steppe, or desert) and for the most part wooded—particularly in the (temperate and) cold humid regions of our globe—the soil scientist is obliged to revert to these natural soil types in order to understand the origin of the most characteristic features of field and garden soil. So it is not surprising that the founders of modern soil science, Ebermayer, Wollny, P. E. Müller, Ramann, the members of the Russian and Finnish schools, Treitz, Albert, Hesselman, and others have paid special attention to the virgin forest and steppe (heath) soils and found there material for a general scientific classification and explanation of soil types.

It seems probable then, that at some very distant future, forestry will be largely based on the care of the native tree-growth (which, however, does not preclude importation of new species over large areas or their more rapid distribution by human means). The study of forest soils, therefore, will likewise deal with virgin soil as formed by the geologically or geographically determined material, under the influence of climatic and biological factors determining the chemical and physical processes which, in the course of time, have produced the particular soil condition present. The necessary introduction into the small, forest-poor countries, like England, Holland, and Denmark, of more intensive forestation, with artificial sowing and planting, mechanical treatment, irrigation, marling, and fertilizing after the same principles as used in agriculture, in order to establish and maintain the forest will on doubt remain an exception in the future, even though these methods and results give very deep understanding of the qualities of forest soils which may also find application in extensive forestry service.

The temperate and cold humid regions, however, presumably present the most numerous and difficult problems for the study of forest soils because *in these localities only* (and from a plant geographical point of view high altitudes must also be included) *are we dealing with one of the most fundamental phenomena in forest soils, i.e., the formation and accumulation of raw humus and the question of the decomposition and treatment of that substance in order to maintain the soil in healthy condition.*

In hot arid districts no appreciable amounts of raw humus are found, and in hot humid districts the dead organic material (plant residue) is transformed so quickly that the question of accumulation does not exist. In such districts the forest soil resembles tilled soil more closely and, if conditions of humidity permit, the forest renews itself naturally unless the indigenous vegetation cover is suddenly removed by a forest fire or too intensive clear cutting. In such cases human intervention may obviate the difficulties, partly through a definite treatment of the forest soil based on principles of forestation and partly through a rational production of the pregrowth of the forest vegetation desired. Still it is often claimed that the disappearance of such forests may become the source of climatic changes and in every case of serious danger from erosion and flood. The cultivation of forests in these localities requires a study of soil conditions whose importance should not be underrated. However, a discussion of these problems is not proposed here.

We may then say that rational forestation is of the greatest importance in the temperate and cold regions of the earth, and, outside of these at such elevations above sea level as have a corresponding climate. To be sure huge forests of great value are to be found in subtropical or tropical districts where the rainfall is great and the soil swampy or very moist from inundations of the rivers, or where irrigation supplies the required amount of water. The great degree of moisture which is a necessary condition for the development of certain trees or tree "associations," however, renders a rational treatment of

the soil by human intervention superfluous or impossible, and forestry in such districts will be confined largely to the most general principles of drainage and the exploitation of those trees which nature has so lavishly bestowed upon mankind. This is to be understood only in a general way. We should not forget, however, that in these warm districts a very intensive forestry may be established also with soil treatment, fertilization, sowing, and planting such as is used in the very important plantations of rubber, palm, and other trees of technical or nutrient value. Still, as has been already stated, the problems of the soil and its treatment here correspond very closely to the problems of agriculture, whereas those which deviate somewhat and form the natural boundary line between forest and field soil, are primarily to be found in the temperate and cold humid regions.

There—under continued colonization of new land or under increased population in earlier settled districts—we find that the best soil has been used for farming, whereas the forests have been relegated to poorer, drier, more sandy soils, or to districts where because they are difficultly accessible (mountains) or the moisture is too great they are not so easily cultivated. Yet this does not preclude the fact that forests still cover wide areas eminently suited to agriculture. In many countries poor in forests, these have been preserved on such soil, among other reasons because forestry has been found to pay as well as or better than farming. It has been observed, however, that when the appropriate kinds of trees are selected (even types which are satisfied with poor living conditions or are resistant to extremes of factors of growth) and when the forest and the soil have been subjected to the proper treatment, it is possible to find or artificially establish forests on poor dry, or poor moist soil. Utilizing such soil for forestry becomes indeed a matter of great economic importance, from which agriculture derives great indirect benefits.

Considered then, as a whole, the study of forest soils presents a series of important problems, scientific as well as practical. These, Zon, has applied to conditions in the United States and listed under separate headings:

1. *The use of soil survey for purposes of mapping forest types and sites and, conversely, the use of forest cover in mapping soil.* We feel that the soil surveys which cover large portions of the country have not been used by foresters in their correlation with forest cover. Similarly, if such a correlation is once established, the natural forest vegetation would be a great help in soil surveys. In a few isolated cases, where attempts at such isolation have been made the results are clear. Our feeling is, that the existing soil surveys can perhaps be made to serve the needs of forestry even more than of agriculture in forest regions.

2. *The relation of forest cover to ground water.* This is a subject which agitated foresters for a long time and is basic to our understanding of the rôle of forests in the circulation of water in the atmosphere. There are classic contributions to this subject by Otozky, Henry and Ebermayer. Recent investigations in Russia brought out the fact that in the case of an abundant flow of ground water the effect of the forest upon the level of ground water was negligible and that in winter there is no difference in the level of ground waters under forests and in the open. These recent investigations do not overthrow but emphasize the earlier ones, that the effect of forests upon ground waters differs in different geographic regions and under different meteorological conditions.

3. *Effect of forest fires upon physical, chemical and biotic qualities of the soil and through them upon the regeneration and growth of different species.* This is a problem which hardly needs elaboration to justify its consideration. In spite of an enormous literature on forest fires, the effects of fires upon soil are little understood. This problem is of special moment in the United States where still on the average for the last ten years there occurred some 80,000 to 90,000 fires annually, which burned over some 16,000,000 acres.

4. *Effect of forest management upon soil properties and through them upon regeneration, growth, and composition of future stands.* The classical example is afforded by the pure stands of spruce in Saxony, where, as a result of successive clear cuttings and plantings to spruce, the soil has deteriorated. It is a well established fact that the leaf litter from pure spruce tends to produce raw humus which has an unfavorable effect on natural reproduction. On the other hand pine mixed with beech, for example, produces a neutral humus, which favors regeneration. The effect of clear cutting on the soil life, particularly of bacteria and earthworms, is well known, and the subsequent effect on natural reproduction. It has now become axiomatic that any silvicultural measure or method of cutting which does not take into account the effect upon the formation of humus and animal life in the soil cannot be successful, no matter how good the silviculture or methods of cutting in themselves may be. Since in this country, natural production will remain the prevalent silvicultural system, the knowledge of how the different methods of cutting affect the soil becomes of vital importance. It is only through treatment of the soil by different methods of cutting that we may hope to obtain successful natural reproduction of the desired species. The importance of this problem cannot be emphasized too strongly.

5. *Soil conditions in swamps in their effects on forest growth and measures for their improvement.*

6. *Agreement upon one most significant and easily determinable soil factor in evaluating forest sites.* There is at present a great divergence of opinion in what are the controlling soil factors in forest sites. Very little work has been done in studying the interrelation of different factors in the variation of their effects in change of one of them. How for instance, does the presence of lime in soils affect the structure, the rapidity of the decomposition of leaf litter, the water-holding capacity of the soils, and the activity of micro-organisms? Each investigator specializes in one special factor, either chemical, physical, or biological, and only few consider the factors all together in their interactions. This leads to considerable confusion and lack of any one single index which would simplify and serve as a key to the whole soil complex.[1] . . . . . .

The aforementioned questions—and many others as well—combine to form a general problem, that of maintaining the forest in a healthy condition and of obtaining the maximum growth of the trees under given geographical and meteorological conditions. To accomplish this it is necessary first to realize fully the factors of growth with which we are dealing, and, insofar as possible, to regulate these factors.

Many people perhaps will be inclined to say at once that mankind is helpless in the face of geographical and meterological conditions. This is a great mistake—at all events, insofar as these factors affect the condition of the soil, for this very soil is a complex of many various factors and exerts the determining influence on the growth of the trees.

Pure meteorological factors, light, temperature, wind, air-humidity, and precipitation, are always limiting factors for all vegetation. These factors,

[1] It is hardly possible to give a single general factor, which is dominant under various conditions, *Fr. W.*

however, react strongly on the soil and, depending on the degree to which this is true, the condition of the soil can be improved or deteriorated by human intervention.

The soil itself, as representative of a series of various factors of growth, greatly resembles a highly complicated organism whose structure and functional interrelationships regulate all plant and animal life. In studying soil, equal emphasis must be placed on its anatomical and physiological characters. Virgin forest soil, in particular, reveals the general basic principles of the anatomy and physiology of all soil, and affords a better opportunity than cultivated soil, which has been totally transformed by the intervention of man, for studying soil processes and the effects on them of single factors.

The "health" of the soil first of all depends on its metabolism being normal. This in turn depends on its structure and on the chemical and physical processes connected with it. On the other hand, the metabolism affects the structure. Structural changes indicate whether the metabolism is normal, whether these changes are caused by "diseased" conditions in the soil organism, such as phenomena of degeneration which cause changes of structure (the podsolization process), or whether degenerate soil will regenerate and again resume its normal condition, under which metabolism is maintained by a certain balance between the processes of catabolism and anabolism.

One important phase in the metabolism of the soil itself, and in that of the flora and fauna found in and on it, is the transformation of the organic matter (carbon) and of the nitrogen compounds. The carbon and nitrogen which form the material substratum for all life development are present on our globe in such relatively small amounts that if life is to be maintained, it is absolutely essential that the natural cycle of transformation of these substances remain unbroken. A partial break very often does occur, however, in the soil, particularly in forests, moors, and other localities where, on this account, humus substances and the organic nitrogen compounds found in them, accumulate. *The most important problem in the study of forest soils is, then, to trace in general the carbon and nitrogen cycle and the factors which influence them.*

Many other questions naturally arise in this connection, among them that of the circulation of the other plant nutrients, but as these are usually either so closely associated with the two above-named all-important substances, or are in themselves necessary factors in their transformation, they may be studied most satisfactorily in connection with them.

The same thing is more or less true of the purely inorganic mineral substances, which, indeed, often form the bulk of the soil and with which so many important properties are associated; namely, the air-content of soil, its permeability to water, its water-holding capacity, its ability to retain by absorption and adsorption certain important plant nutrients (by acid and base exchange), its reaction and buffer content, and its specific heat and specific conductivity for heat. These properties vary with the size of particles in the soil and their distribution, with the content of inorganic colloids, such as iron and aluminum

hydroxides and colloidal silica, with the content of various minerals, with the degree of the weathering process, and with the distribution of the minerals through various depths. Some of the same properties, however, are characteristic of organic colloids and to a certain extent these may act as substitutes for the inorganic compounds.

On the whole the interaction between the inorganic and the organic substances in the soil is very close, and in studying forest soil all separate components must be taken into account. Only in forest soils in cold (and temperate) humid regions do the organic substances play a dominant part in comparison with the part they play in farm soil. On account of the longevity of the vegetation form, and the long periods of rotation with which forestry deals and the attendant longer undisturbed periods to which the soil is submitted, the problems, and in part too, the methods of investigation presented to scientists studying forest soils are very special.

In this short summary it is possible to indicate only some of these important problems and the methods by which they may be investigated. The following outline may suggest the natural limits of the study of forest soils, and to some extent justify the forming of a special section for forest soil in the International Society of Soil Science.

The majority of soil investigations may probably be grouped under one or more of the following divisions:

1. *Geological description, genesis, and mapping.*
2. *Mechanical analysis and physical investigations.*
3. *The depth and movement of ground water.*
4. *Inorganic substances.*
    a. Weathering process.
    b. Base and acid exchange. The phenomena of absorption.
    c. Content and distribution of inorganic plant nutrients.
    d. Content and distribution of carbonate of lime and other buffers.
    e. Content and distribution of inorganic colloids (adsorption).
    f. Reaction.
5. *Organic substances. The carbon and nitrogen cycle.*
    a. The amount and distribution of organic matter. Humus.
    b. The organic acids and colloids and their influence on reaction, power of adsorption, and the phenomena of podsolization.
    c. The processes of humus decay; mineralization of the organic substances (the decomposition of cellulose, lignin, and humus.)
    d. The amount, kind, and distribution of nitrogen compounds and their formation; fixation of free nitrogen, formation of humus ammonia and nitrate nitrogen.
6. *Organisms in the soil.*
    a. Worms, larvae, protozoa, etc.
    b. Bacteria.
    c. Fungi (mycorrhiza).
    d. Roots, leaves, and other residue of higher plants; the dependence of the microcosm on the species of the organic residue, on the reaction, the inorganic nutrients, etc.

7. *Correlation between the treatment of the forest, the tree stands, the herbaceous flora, and the condition of the soil.* Under this division many details are considered; namely, admission of light, conditions of moisture and heat, and effect of wind, which depend very largely on human intervention.

It is evident that it is impossible for the student of forest soils to confine himself to a single one of the problems mentioned here. As a rule, many must be considered simultaneously and several methods of investigations used. *And just as practical forestry, in most instances, differs from practical agriculture and horticulture and requires a very different training, the scientific statement of the problems and the method of research for their solution are different from those used in field and garden soils.*

The scholar wishing to work scientifically and independently with the problems of forest soils should be thoroughly trained in the methods of investigation of natural sciences (geology, physics, chemistry, botany, zoology, and microbiology), and possess intimate knowledge of practical forestry (including culture of forest trees, pure stand of single tree species, of mixed stands, of the underbrush and herbaceous flora of the forest, density of planting, thinning out, rotation). There is probably no other branch of agriculture where intimate coöperation between applied science and pure science is so necessary.

SIXTH COMMISSION

THE APPLICATION OF SOIL SCIENCE TO LAND CULTIVATION[1]

The work of this commission naturally falls into three groups of studies, namely, Irrigation, Drainage, and Erosion. A special subcommission was organized at the Congress in Washington for the study of the utilization of peat soils.

In connection with the problems of irrigation it has been decided that more detailed information is essential, before it is known how irrigation may be carried out to the best advantage for different soils and conditions, whether by means of open ditches, through a sprinkling system, or through an underground supply of water. It is also important to determine the effect of irrigation on certain physical and chemical characteristics of the soil.

A study of the contributions submitted on drainage reveals the fact that the depth of drains usually varies between 1.0 and 1.5 meters, depending upon local conditions. In order to determine distance between drains, it is necessary to carry on tests on mechanical soil analysis and groundwater investigations. The mechanical soil analysis recommended for purposes of technical practices is the elutriation method of Kopecki, retaining the four groups of drain sizes suggested by him. For determining the most advantageous drainage system and its efficiency, it is recommended that governments follow the suggestions of Fauser for the construction of experimental drainage fields. The results obtained should be reported, annually if possible, to the Sixth Commission. The technical institutes which deal with drainage operations are invited to obtain data concerning increases in yields and values of drained soils according to the manner of Biji and submit the results likewise to the Sixth Commission for publication.

Works for the prevention and control of erosion, which is a matter of much importance to many countries, have been constructed according to empirical rules, but it is desirable that experiments be undertaken to determine the laws which should govern the construction of such works.

A. P. Dachnowski-Stokes of the Department of Agriculture in Washington has been entrusted with the formation of the subcommission for the study of peat lands. An attempt will be made to secure for the next Congress the uniformity in nomenclature and methodology which is required for practical and scientific investigations in peat problems.

[1] This article was prepared from a report submitted by J. Girsberger, president, and S. H. McCrory, vice-president.

SUBCOMMISSION FOR THE STUDY OF PEATLANDS

A. P. DACHNOWSKI-STOKES[1]

Chairman

(U. S. Department of Agriculture, Bureau of Chemistry and Soils)

The First International Congress of Soil Science has provided an unusual opportunity to American investigators of peatland problems. It was possible not only to meet leading peat specialists from Europe, but to come together as well for the interchange of views and ideas, and amiably to discuss the international questions which arise in the study and utilization of areas of peat.

There can be no doubt about the timeliness and the importance of the conference. The content of information from peat institutes is growing rapidly and the publications by peat specialists are numerous, in particular the profile studies of peatlands in the Scandinavian countries, in Germany, Austria, and Russia. Areas of peat are today one of the greatest undeveloped land resources. They express in their morphological features a definite and intimate relationship to geographical conditions of a former period and to forces which determined the character and distribution of plant life in the past. In addition, areas of peat constitute a storehouse of raw materials for agriculture and certain phases of industry.

To give the delegates and visitors a practical comparison and demonstration of the character of organic materials and the status of the research carried on at present, an exhibit was prepared, showing different types of peat and peat products, photographs and diagrams of profile sections, and the instruments and methods used in peat investigations in this country. The exhibit included also two monolithic sections from a German "highmoor" and a series of peat samples from four corresponding layers of the moors in Ireland, Holland, Austria, and Czechoslovakia, to illustrate the stratigraphical evidence on which a correlation of the European highmoors in an east-west belt may be based.

At the second session of the Sixth Commission a petition was communicated to the members with regard to the formation of an International Peat Society. Informal conferences with directors of peat institutes and specialists in several countries of Europe indicated a general desire for an organization which might attempt to clear up misunderstandings and the confusion in terminology, and promote the adoption of uniform methods in peat investigations. This proposal was expressed in a letter from the author which he addressed to the Executive Committee of the Congress, but was left with the Sixth Commission for further consideration and action.

[1] Associate Physiologist.

After a preliminary discussion a resolution was approved unanimously to organize within the Sixth Commission a subcommission for the study of peat-lands. With the view of obviating delay and achieving satisfactory results as soon as possible, the following men were appointed to administer the work of the subcommission: A. P. Dachnowski, U. S. Department of Agriculture, chairman; Hugo Osvald, Jönköping, Sweden, secretary; B. Tacke, Germany; J. Girsberger, Switzerland; L. von Post, Sweden; S. H. McCrory, Washington, D. C.; F. J. Alway, Minnesota, U. S. A.; W. S. Dokturowski, and A. Kirsanov, U. S. S. R. (Russia); F. E. Clements, Carnegie Institution, Washington, D. C., U. S. A.

At the opening of the third session of the Sixth Commission a report was read and accepted relative to the organization and activities of the peat sub-commission. The general scope was indicated to be as follows:

> The Subcommission proposes to maintain relations on an international basis with institutions interested in peatland problems, to encourage and assist in cooperative peat investigations or continuous group research, and to aid in coordinating data and experimental results obtained upon well identified peatlands in different countries. An International Peat Committee of the Sub Commission, organized on a basis of divisional activities, is to offer suggestions and recommendations for consideration and approval, and aid in making up the program for the future sessions of the Soil Science Congress.

On the following day, June 18, the first international meeting so far as is known, dealing wholly with subjects related to peatland agriculture, was held. Papers were contributed by W. Wolf, Germany; Hugo Osvald, Sweden; J. G. Byil and D. J. Hissink, Holland; B. F. Haanel, Canada; V. R. Burton and P. M. Harmer, Michigan; T. J. Sievers, Washington; J. H. Beattie and A. P. Dachnowski, Washington, D. C.

The entire program had been arranged to foster the comprehension of one another's distinctive efforts, purposes, and needs. As one of the results, American investigators have come to appreciate more fully the European view-point; they have acquired a larger knowledge of the activity in peat investigations on the other side of the Atlantic. European peat specialists have, for their part, become familiar not only with the several chief types of peat found in North America and the instruments and methods used in the United States, but also with the feelings of warmest cordiality and good will which prevail among the scientists of this country with respect to their European co-workers.

During this session a resolution was offered and approved that a national or American section be formed within the peat subcommission, and that a committee be empowered to appoint a chairman, regional vice-chairmen, and a secretary to conduct the activities of the American section. The following were selected as officials of the American section: chairman, F. J. Alway; secretary, J. H. Beattie; vice-chairmen, A. F. Gustafson, L. G. Willis, P. Harmer, W. L. Powers, J. S. Burd, and R. V. Allison.

It was further approved that the International Peat Committee of the sub-commission be requested to prepare a draft relative to securing uniformity in

international methodology and nomenclature required for research and technical procedures in peatland problems and to report its recommendations to the next soil science congress.

Possibly of even greater value and interest than the general session, were group conferences which discussed specifically, different types of peat, field and laboratory methods, and the general growth and progress in peatland agriculture. These events offered opportunity for further discussion with the representatives of Europe and Canada, many of whom have never before had occasion to visit this country.

To highway and drainage engineers and to workers concerned with the augmenting of crops, timber, and pasture, the first international peatland conference will be undoubtedly a source of especial gratification. It is felt that concrete benefits have been derived by all parties and that the path is made easier for international progress in the handling of peatlands of like character in different countries.

Naturally the effects of a conference such as this are not immediate; nor can any radical change be expected in international peat investigations as a result of the first session. But when it is considered that this gathering has been truly an interstate and an international conference, treating peatland problems in a practical way, it will be seen that its achievements in minimizing difficulties and breaking down barriers of terminology are of a genuinely substantial nature. The decision to take an active part in promoting research and in coördinating the information to the end that we may obtain a broad, international perspective of peatland agriculture, marks a real stage in progress.

It is anticipated that the division of labor in the International Peat Committee will lead its respective members to prepare for the next congress reports and recommendations concerning questions which, on the one hand, tend strongly in the direction of special scientific phases, such as geology, ecology, paleobotany, and stratigraphy, or, on the other hand, tend in the direction of the technique of reclaiming and improving areas of peat having well identified profile features.

It is probable that recommendations will be put forward for the setting up of a chain of regional stations in different countries for the purpose of investigating special phases of peatland problems under different climatic conditions. Of immediate concern is the question pertaining to the adoption of uniform methods of the analysis of peat materials, and of a procedure for determining easily and reliably the characteristic properties of main types of peat and some of their transition stages. The usefulness of standardization and uniformity is not limited to reducing the least necessary terms and methods; it is applicable to varieties and grades of peat material as well. The advantages to engineering and other technical services are very great, as it becomes possible to place the application of scientific technique to field practices on an effective and economic footing.

Another basic study which possesses particular interest concerns profile

analyses. It comprises the discovery of the relations which exist between regional environmental conditions and the physical, chemical, and biological changes going on in successively lower layers of an area of peatland under specific cultural and cropping practices. This objective is well worth the united exertion of many investigators, for in consequence, a fuller realization can thus be obtained of the effects of systems of drainage, irrigation, or fertilizer experiments under distinctive climatic conditions. The next meeting of the peat subcommission will be devoted to a definite program of selected subjects, among them a plan of procedure for international coöperation.

GENERAL EXHIBITS

E. TRUOG

Chairman

(University of Wisconsin, U. S. A.)

In the spring of 1925 the President of the Congress suggested having exhibits of soil acidity apparatus and methods at the First International Congress of Soil Science and asked the writer to act as chairman of a committee to handle the matter. The idea proved so fertile that by the time the congress was held the exhibits had grown to include practically the whole field of soil science. Four large rooms with a total floor space of approximately three thousand square feet in the United States Chamber of Commerce Building were assigned to the exhibits. This space, however, proved so insufficient, that the exhibits overflowed into the corridors and even out into the open court.

It was the splendid coöperation of the foreign delegates and visitors, and the soil workers and apparatus companies of this country that made the exhibit so extensive, varied, and valuable in many ways. The value of the exhibit was amply demonstrated by the large crowds that visited it from the first to the last day of the congress. In fact the exhibit gave one a new vision of the extensiveness of soil science and of the varied nature of the research work on soils which is being done in different countries.

On entering the building and going down the corridor to the left, one came first to the exhibit of American soil literature, which filled one of the smaller exhibit rooms. A corner of this display is shown in plate 8, figure 1. The exhibit is described in the following article of this issue of *Soil Science*. Miss Claribel R. Barnett, librarian, Agricultural Library, United States Department of Agriculture, who was in charge of this exhibit, had on hand for free distribution *A Classified List of Soil Publications of the United States and Canada*, consisting of 549 pages, which she and her assistants had prepared especially for this congress.

At the next door to the left, one came to the Executive Office of the Congress but which of necessity had also to be used for exhibits. Prof. H. Stremme of Danzig covered two walls of this room with an extensive display of elaborate and detailed soil maps. Along another side of this room was displayed an excellent and carefully planned exhibit from Latvia, which was sent over by J. Wityn, who unfortunately could not attend the congress. This exhibit (plate 8, fig. 2) included a large number of colored soil profiles on which was shown the influence of vegetation, drainage, and other factors in the development of soils. Eighteen large soil monoliths were also displayed. Wityn specially

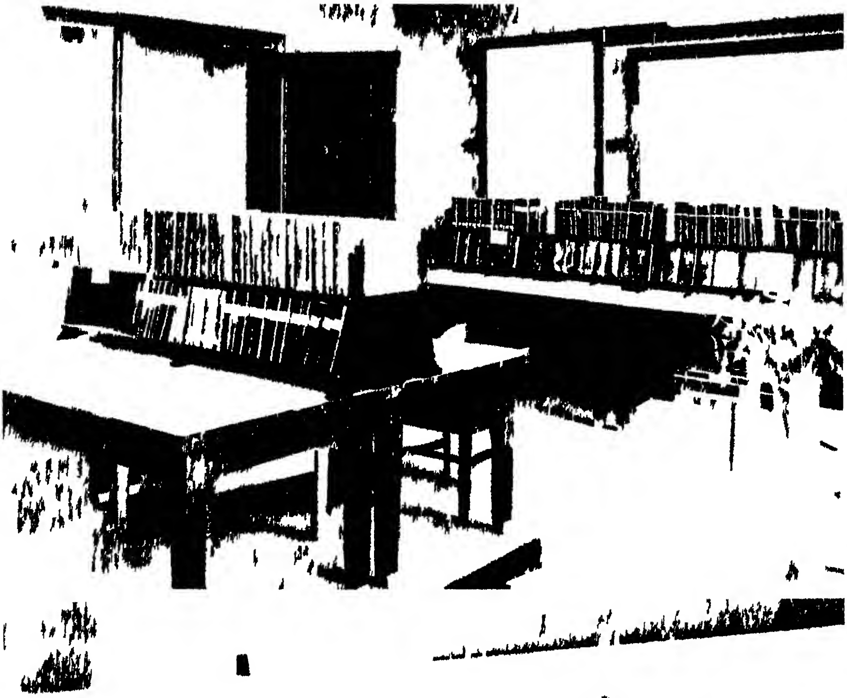
prepared for this congress an excellent and rather complete bulletin relating to the soil investigations of Latvia. A supply of this bulletin was on hand for free distribution.

Down the corridor, in the next room to the left was located one of the outstanding exhibits, which was presented by the Russian delegates. Unfortunately their large and elaborate exhibit of soil monoliths was delayed in transit and did not arrive in time to be displayed. Their display of soil maps and soil literature was so large that it entirely filled a room 20 feet by 40 feet. K. D. Glinka and Boris Polynov of Leningrad, Russia, were largely responsible for this exhibit which made one feel that the Russian soil scientists have a rightful claim to leadership in the field of soil classification and mapping. A large number of scientific papers dealing with soil chemistry and plant nutrition were shown. Many of these are not available in the libraries of our agricultural colleges. However, most of this literature has been given to the agricultural library of the U. S. Department of Agriculture, and most of the maps and charts have been given to the U. S. Department of Agriculture. Because of the nature of the material and the arrangement of the room, it was not practicable to take a picture of this display.

At the end of the corridor a large corner room, 30 feet by 60 feet was completely filled with a variety of displays. Plate 9 and plate 10, figure 1 show a portion of this room and give an idea of the nature and extent of the exhibits in this room. Plate 10, figure 1 shows in the foreground some general apparatus used in soil investigation. To the right across the aisle was another table covered with more apparatus of this nature. This general apparatus was exhibited by the Central Scientific Company of Chicago, and Eimer and Amend of New York City. On the wall and table to the left is shown a display relating to peat investigations. This display was in charge of A. P. Dachnowski and Stokes, of the United States Bureau of Plant Industry. On the wall and table in the distance to the right was displayed the very ingenious dynamometer from the Rothamamsted Experimental Station, of which B. A. Keen was in charge.

Plate 9, figure 2 shows another corner of the large exhibit room. On the table in the center is an elaborate display of electrometric and colorimetric apparatus for the determination of hydrogen-ion concentration, exhibited by Leeds and Northrup of Philadelphia and LaMotte Chemical Products Company of Baltimore. The few microscopes in the foreground are just a suggestion of the elaborate display of special microscopes, colorimeters, and other optical apparatus which were furnished by Bausch and Lomb Optical Company, E. Leitz, Incorporated, Spencer Lens Company, and Carl Zeiss, Incoporated.

On the wall to the right is shown a portion of the extensive exhibit illustrating strain variations in root-nodule bacteria. This exhibit was in charge of I. L. Baldwin and W. H. Wright of the University of Wisconsin. Professor Wright also demonstrated the use of his modified Chambers' Micor-Manipulator for isolating single cells of bacteria.



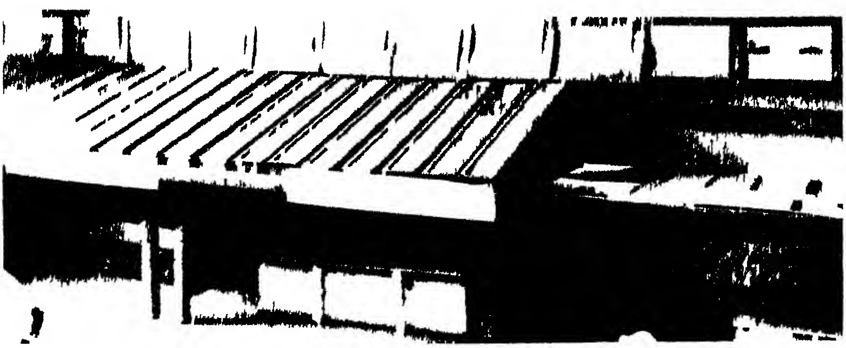


FIG 1 A corner of the exhibit of American soil literature
FIG 2 Soil profiles and monoliths from Latvia

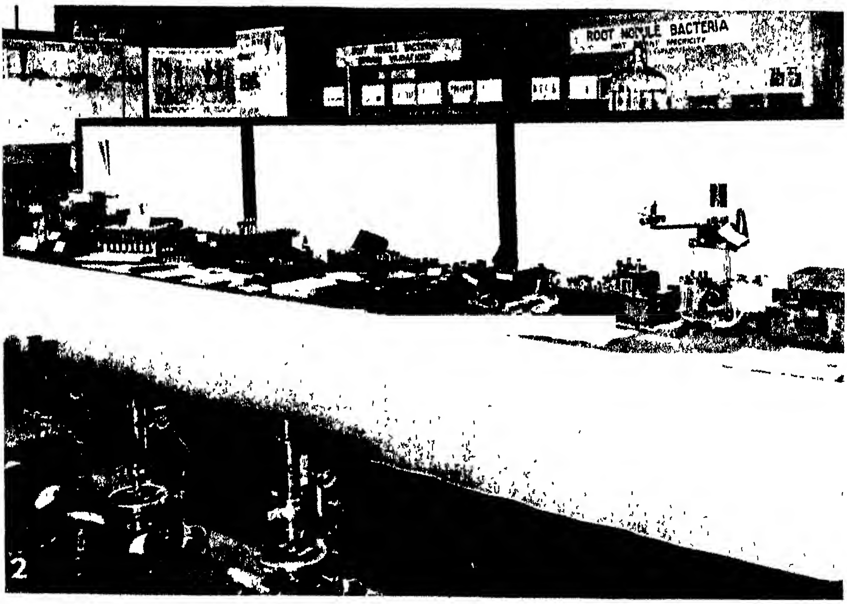


Fig. 1. A view of the large exhibit room illustrating on the table to the left the triangular method of fertilizer experiments, and on the table and wall in the distance, soil erosion problems and control.

Fig. 2. Another corner of the large exhibit room showing apparatus for the colorimetric and electrometric determination by hydrogen-ion concentration.

In this same corner, but not shown in the picture, G. Steiner of the United States Bureau of Plant Industry exhibited his revolving, round, microscope table. With this table the student or investigator, from the same seat, by simply revolving the table, may have different microscopes loaded with various specimens brought before him. Nearby was an interesting exhibit of both root and aerial nodules. This was in charge of Dr. N. R. Smith of the United States Bureau of Plant Industry.

In plate 9, figure 1 is shown a view down one side of the large exhibit room. Water cultures on the table to the left illustrate the triangular method of fertilizer experiments. At the end of the table are shown some pot tests of the fertilizer value of manganese. These cultural experiments were exhibited by O. Schreiner, of the United States Bureau of Plant Industry. Colored pictures on the wall and a model on the table in the distance illustrate soil erosion problems and methods of control.

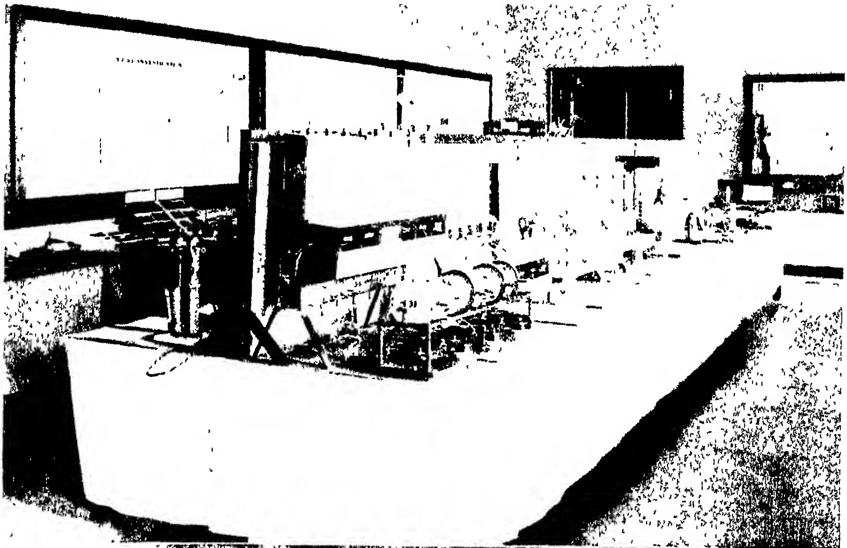
In this short article it is impossible to describe or show by pictures all of the exhibits, especially in the large exhibit room. A few more should, however, be mentioned: viz., a display of Pyrex glass by Corning Glass Works; a soil sampler and a modified Wiegner tube by R. Bradfield of Missouri: an auto-irrigator by E. P. Deatrick of West Virginia; miscellaneous special physical apparatus by C. H. Spurway and G. J. Bouyoucos of Michigan; the cornstalk method of determining fertilizer needs by G. N. Hoffer of Indiana; apparatus for determining the oxygen-supplying power of the soil by L. Hutchins of the United States Bureau of Plant Industry; a minature plant for fixation of atmospheric nitrogen by the Fixed-nitrogen Laboratory of the United States Bureau of Soils.

In the corridor leading to the open court was displayed the set of soil monoliths shown in plate 10, figure 2. These came from Hungary and were in charge of Peter Treitz, of Budapest. Their particular interest lay in the fact that the soil was conserved in its natural state by means of a new method devised by Sigmund Pinkert, of the Royal Hungarian Geological Survey. This method makes possible the collection and preservation of natural soil-type specimens in very thin sections, thus enabling the specimens to be transported and handled very easily and without danger of damage. The special process used fixes the soil in its natural condition so that the columns may be set upright without any danger of the soil falling out, even though the face of the columns are not protected with glass. Details of this method can be obtained from either Treitz or Pinkert.

The United States Bureau of Soils displayed numerous large soil monoliths in the open court and many soil maps in an adjacent corridor.

Unfortunately it is not possil le to mention all the exhibits and all those who coöperated so splendidly in helping to make the exhibits a success. Special mention should be made of the part played by W. W. Weir of the United States Bureau of Soils and F. L. Goll, physiologist of the Bureau of Plant Industry. These men were largely responsible for arranging and placing the

material. F. L. Goll also shouldered the great responsibility of dismantling and returning much of the material. Many thanks are due Mr. Shipman, superintendent of the United States Chamber of Commerce Building, who gave the exhibit committee his most hearty and immediate personal attention in handling the numerous perplexing problems which arose.



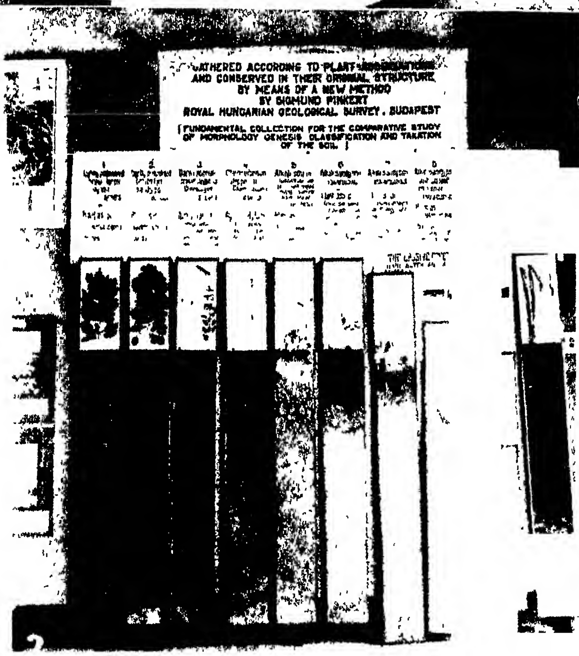


FIG. 1. A corner of the large exhibit room showing general apparatus for soil investigation.

FIG. 2. Natural soil profiles with vegetation from Hungary, collected and preserved by means of a new method.

THE LIBRARY EXHIBIT

CLARIBEL R. BARNETT

(Librarian, U. S. Department of Agriculture)

The Library Exhibit at the First International Congress of Soil Science was arranged by the Library of the U. S. Department of Agriculture, and members of the library staff were in attendance during the Congress. The exhibit was conveniently located in Room E of the Chamber of Commerce of the United States, near the main entrance. Panels were hung on all four sides of the room. On these panels photographs, printed matter, diagrams, and legends were displayed. On the west side of the room were two exhibit cases in which old books were shown under glass. In the center of the room were two reading tables placed back to back with book racks in the center. Tables and book racks were also placed on the east side of the room under the panels.

There were three main purposes in the exhibit. An attempt was made, first, to picture the development, historically, of American soil science; second, to show the current literature on the subject with some of the more important aids in its use; and third, to serve as a reading and reference room during the Congress.

In picturing the historical development of soil science in the United States the three wall panels on the east side of the room were used to call attention to important dates in this development and to persons connected with this development. These dates were arranged in three groups under the following headings: 1. Early Agrogeological Surveys, 2. Early Professorships of Agriculture and Agricultural Chemistry in the United States, and 3. Official Steps in the Development of Soil Science in the United States. Under the dates were photographs of the persons whose names stand out in agricultural history in connection with these dates. Following are the dates and legends shown on the three panels under the three respective groups:

AGROGEOLOGICAL SURVEYS

1821

T. ROMEYN BECK—AMOS EATON

Joint authors of a geological survey of the county of Albany, New York—1821

The Survey, taken under the direction of the agricultural society of Albany, was published in the first report of the New York Board of Agriculture, 1821. The preface states that "It is the first attempt made in this country, to collect and arrange geological facts, with a direct view to the improvement of agriculture."

1830

EDWARD HITCHCOCK

Director of the First State Geological Survey

To Massachusetts belongs the credit of having inaugurated and carried to successful completion under state auspices the first geological and natural history survey on the western continent, in 1831. Professor Edward Hitchcock of Amherst College was in charge of this survey and made the first report, January 1, 1832.

EARLY PROFESSORSHIPS OF AGRICULTURE AND AGRICULTURAL CHEMISTRY IN THE UNITED STATES

1792

SAMUEL L. MITCHILL

Professor of Natural History, Chemistry and Agriculture at Columbia University -1792

As far as known this is the first professorship of agriculture in the United States.

1846

JOHN PITKIN NORTON

Professor of Agricultural Chemistry at Yale University -1846

First professorship of agricultural chemistry in the United States.

1855

SAMUEL WILLIAM JOHNSON

Professor of Agricultural Chemistry, Yale University

Sometimes called the "Father of Agricultural Science" in the United States.

OFFICIAL STEPS IN THE DEVELOPMENT OF SOIL SCIENCE IN THE UNITED STATES

1796

GEORGE WASHINGTON

First President of the United States

In his Address to the Congress in 1796 Washington strongly urged the establishment of a National Board of Agriculture.

1839

HENRY LEAVITT ELLSWORTH

First Commissioner of Patents

"Father of the Department of Agriculture"

In 1839 Ellsworth secured the first agricultural appropriation from Congress. This resulted in the formation of the Agricultural Division of the Patent Office which later developed into The Department of Agriculture.

1862

Isaac Newton

First Commissioner of Agriculture

The bill establishing a Department of Agriculture was signed by President Lincoln May 15, 1862.

1862

Justin L. Morrill

U. S. Senator from Vermont

The Morrill Act providing for the establishment and endowment of State Agricultural Colleges was signed by President Lincoln July 2, 1862.

1887

William H. Hatch

U. S. Representative from Missouri

The Hatch Act providing Federal aid for Agricultural Experiment Stations in all the states was signed by President Cleveland March 2, 1887.

1889

Norman J. Colman

First Secretary of Agriculture

In 1889 the Department of Agriculture was raised to the first rank in the Executive Branch of the Government.

1894–1901

Milton Whitney

Chief, Bureau of Soils

The Division of Soils (formerly the Division of Agricultural Soils in the Weather Bureau) was established in 1894 as an independent division of the Department with Professor Milton Whitney as Chief. In 1901 the Division was raised to the rank of a Bureau.

In addition to the panels picturing the historical development of American soil literature, a number of books representative of different periods were exhibited. These were divided into six groups. In the first group were included a number of the earliest books on agriculture published in this country. A list of the books follows:

Eliot, Jared. 1685–1763.

Essays upon field husbandry in New England, as it is or may be ordered. Boston, Printed and sold by Edes and Gill, 1760. 166 pages.

"The foregoing essays were first printed in New London and in New York; the first in 1748, 2d in 1749, 3d in 1751, 4th in 1753, 5th in 1754, 6th in 1759." p. 158. (In Library of Congress)

Essays upon field husbandry. [New ed. Boston, 1811]

(In Papers for 1811, communicated to the Massachusetts society for promoting agriculture, pp. 9–104.)

Bordley, John Beale. 1727–1804.

Summary view of the courses of crops, in the husbandry of England and Maryland, with a comparison of their products, and a system of improved courses, proposed for farms in America. Philadelphia, Printed by Charles Cist, 1784. 12 pages.

(Published anonymously)

Sketches on rotations of crops and other rural matters. Philadelphia, Printed by Charles Cist, 1797. 76 pages.

Essays and notes on husbandry and rural affairs. The second edition, with additions. Philadelphia, Printed by Budd and Bartram, for Thomas Dobson, 1801. 536+8 pages.

(The first edition was published in 1799)

Spurrier, John, of Brandywine Hundred, Delaware.

The practical farmer, being a new and compendious system of husbandry, adapted to the different soils and climates of America, containing the mechanical, chemical and philosophical elements of agriculture. Wilmington, Printed by Brynberg and Andrews, 1793. 360 + XV pages.

Peters, Richard. 1744–1828.

Agricultural enquiries on plaister of Paris; also facts, observations and conjectures on that substance, when applied as manure. Collected chiefly from the practice of farmers in Pennsylvania, and published as much with a view to invite, as to give information. Philadelphia, Printed by Charles Cist and John Markland, 1797. 111 pages.

Logan, George. 1752–1821.

Fourteen agricultural experiments to ascertain the best rotation of crops, addressed to the "Philadelphia Agricultural Society." Philadelphia, Printed by Francis and Robert Bailey, 1797. 41 p.

(In Library of Congress)

Binns, John A., of Loudon County, Virginia.

A treatise on practical farming; embracing particularly the following subjects, viz: The use of plaister of Paris with directions for using it and general observations on the use of other manures; On deep ploughing; Thick sowing of grain; Method of preventing fruit trees from decaying, and Farming in general. Frederick-Town, Maryland, Printed by John B. Colvin—Editor of the Republican Advocate, 1803. 72 pages.

Moore, Thomas, of Maryland.

The great error of American agriculture exposed: and hints for improvement suggested. Baltimore, Printed by Bonsal and Niles, for the author, 1801. 72 pages.

Taylor, John. 1750–1824.

Arator: being a series of agricultural essays, practical and political, in sixty-one numbers. by a citizen of Virginia. Georgetown, Columbia, Printed and published by J. M. and J. B. Carter, 1813. 296 pages.

(Published anonymously)

Ruffin, Edmund. 1794–1865.

Essay on calcareous manures. Petersburg, Va., 1832.

(Preface: The theoretical opinions supported in this essay together with my early experiments with calcareous manures were published in the American Farmer (vol. 3, p. 313), 1821.)

In the second group of publications were displayed publications of early agricultural societies of the United States and also early agricultural periodicals. The societies included were the Philadelphia Society for the Promotion of Agriculture (established 1785), Agricultural Society of South Carolina (organized 1785), the Society Instituted in the State of New York for the Promotion of Agriculture, Arts and Manufactures (established 1791), the Massachusetts Society for Promoting Agriculture (incorporated 1792), and

the Pennsylvania Agricultural Society (incorporated 1823). The publications of these societies which were exhibited ranged in date from 1792–1815. All contain numerous articles in regard to soils. The copies of the Transactions of the New York Society which were shown had an added interest because of their former ownership. One of the volumes formerly belonged to Simeon De Witt, a member of the Society, and the other to Elkanah Watson, often called "the father of agricultural fairs." The two pioneer American agricultural journals which were shown, were the *Agricultural Museum*, the first number of which was published in "Georgetown, Ca." the 4th of July, 1810, under the editorship of David Wiley, and the *American Farmer*, generally referred to as the first American agricultural journal, the first number of which was published April 2, 1819, in Baltimore, Md., under the editorship of John Stuart Skinner.

A third group of publications illustrated the next stage in the development of American soil literature. This included books issued subsequent to 1840 (the date of the publication of Liebig's *Organic Chemistry in its Applications to Agriculture and Physiology*), and previous to the establishment of the state experiment stations. The three following books were among the most important milestones of this period:

Dana, Samuel Luther. 1795–1868.
Muck manual. Lowell, D. Bixby, 1842. 242 pages.
Dr. E. F. Smith in his recent book on "Old Chemistries," refers to this book as "the first volume written in America on a very interesting division of chemical science, that is, agricultural chemistry."

Norton, John Pitkin. 1822–1852.
Elements of scientific agriculture; or, The connection between science and the art of practical farming. Albany, E. H. Pease and company, 1850. 208 pages

Johnson, Samuel William. 1830–1909.
Essays on peat, muck and commercial manures. Hartford, 1859. 178 pages.

In a fourth group were included early agrogeological surveys. A. C. True has pointed out[1] that "before the establishment of the first agricultural experiment stations in the United States there were Geological Surveys in about thirty states. Most of these states collected and published data directly related to the agriculture of their respective states. They thus lent a considerable foundation for the most intensive work of the experiment stations on soils and fertilizers in their relations to plant growth." In addition to the agrogeological survey of Albany County in 1821 by T. Romeyn Beck and Amos Eaton and the Massachusetts Geological Survey of 1831 there was shown a set of early reports of the Kentucky Geological Survey, 1854–1859. These were lent for the exhibit by Alfred M. Peter of the Kentucky Agricultural Experiment Station who also sent the following statement in regard to them:

These volumes of the Kentucky Geological Survey record the earliest systematic chemical study made in the United States on a large scale, of the soils of a large area. Samples were

[1] In an unpublished manuscript.

taken systematically of the virgin soil, cultivated soil of the same kind near by, and sub-soil, from many places in Kentucky. The soil was also correlated with the geology. Comparative analyses showed a distinct diminution in the percentages of mineral plant food in cultivated soils, as compared with the virgin soils of the same kind. Characteristic differences were found in the soils of different geological horizons. The investigation was planned by Dr. Robert Peter of Transylvania University, Lexington, Ky., Chemist of the Kentucky Geological Survey, with the approval of Dr. David Dale Owen, Director. The analyses were made by Dr. Peter, who accomplished an unusual amount of work by carrying on twenty or more analyses at the same time. The work was begun in 1854 and continued until 1860. The analyses of soils are scattered through the four chemical reports . . . . . These volumes are the reference set kept by Dr. Robert Peter, in the laboratory.

One of the first official recognitions of the importance of soil analysis was the establishment by the Legislature of Maryland in 1847 of the position of agricultural chemist for the state. A copy of the first report of James Higgins, who was the first to occupy this position, was shown in the exhibit. The Tenth Census volumes containing the "Report on Cotton Production in the United States also embracing agriculture and physico-geographical descriptions of the several cotton states and of California" by Eugene W. Hilgard, were also shown because of their historical importance.

In the fifth group were shown American editions of the works of Chaptal, Sir Humphrey Davy, and Liebig as a reminder of the influence which these pioneers in soil science had upon the development of soil science in America. Included also in this group were Glinka's *Die Typen der Bodenbildung* issued in 1914, with the English translation by C. F. Marbut. Accompanying the translation was the following statement, prepared in the Bureau of Soils, on the importance of this book on the recent development of soil science in this country:

In the early work of the Soil Survey division of the Bureau of Soils, the differentiation of soils was based on texture, because soil texture was regarded as the dominant factor affecting crop production. At that time it was not thought that a soil science could be associated with the survey of soils.

As the work of the Soil Survey advanced, it was soon found that color, drainage, geological origin, and the character of the parent material were other factors that should be considered in soil survey work. Until 1914 the work had proceeded on the basis of soils as geologic materials, no one having thought of soils as natural bodies developed from geologic materials and as products of soil-forming forces.

In 1914 Dr. Glinka's book, *Die Typen der Bodenbildung*, was published and a few copies reached the United States before the outbreak of the World War. During the period of the war, the effect of this book resulted in the changing, somewhat, of the boundary lines of the soil provinces which the Soil Survey of the United States had defined according to geological, topographical, and physiographical features of the country.

The most important idea advanced by Dr. Glinka in his book is that the characteristics of a type of soil may be determined only by a study of soil profiles. This idea has led to most fruitful results in the Soil Survey, in that types of soil are now differentiated and classified according to the characteristics exhibited by soil profiles. The characteristics thus observed are the results of soil-forming forces acting on geologic material and constitute the bases of a genetic or natural classification of the soils of the country. This epoch-making book of Dr. Glinka's has been an extremely helpful influence in the study of soil classification.

The sixth and last group of publications comprised a collection of recent soil literature of the United States consisting of a complete set of the soil publications of the U. S. Department of Agriculture, a select but extensive set of the soil publications of the State Experiment Stations furnished by the various states, complete sets of *Soil Science* and the *Journal of the American Society of Agronomy*, sets of the Geological Surveys of Maryland and Wisconsin, and the recent books on soils published in the United States which are now in print. These recent books and bulletins were on the book racks on the tables where they could be conveniently used for reference. Two wall panels near these tables were used for calling attention to the guides in the use of current American soil literature. A list of the guides follows:

Experiment Station Record, published by the Office of Experiment Stations, U. S. Department of Agriculture.

Agricultural Index, published by the H. W. Wilson Company, New York.

Chemical Abstracts, published by the American Chemical Society.

Biological Abstracts, published under the auspices of the Union of American Biological Societies.

Agronomy Current Literature, compiled by the staff of the Bureau of Plant Industry Library from publications received in the U. S. Department of Agriculture Library.

Official Record of the U. S Department of Agriculture in which are listed each week new publications of the U. S. Department of Agriculture and State Experiment Stations, and the Principal Library Accessions.

Monthly Catalogue, United States Public Documents (with prices) issued by the Superintendent of Documents.

Soils and Fertilizers, Price List 46 of the Superintendent of Documents, Government Printing Office. Lists government publications available for purchase.

Post card announcements of new publications of the U. S. Department of Agriculture.

Bibliographical Contributions of the U. S. Department of Agriculture Library:

- No. 12, Peat, a Contribution towards a bibliography of the American Literature through 1925.
- No. 13, a Classified List of Soil Publications of the United States and Canada.
- No. 14, List of the Publications on Soils issued by the United States Department of Agriculture, 1844–1926.
- No. 15, List of the Publications on Soils issued by the State Agricultural Experiment Stations of the United States through 1926.

The last three *Bibliographical Contributions* were especially prepared by the Library of the Department of Agriculture for the Soil Congress. Copies of these and of *Bibliographical Contribution* no. 12 are still available on request.

THE TRANSCONTINENTAL EXCURSION

A. G. McCALL

Executive Secretary of the American Organizing Committee

(U. S. Department of Agriculture)

The transcontinental excursion which followed the meetings of the First International Soil Congress in Washington proved to be a fitting climax to the program which had been arranged by the American Organizing Committee. The thirty days of personal contact during the excursion served to cement

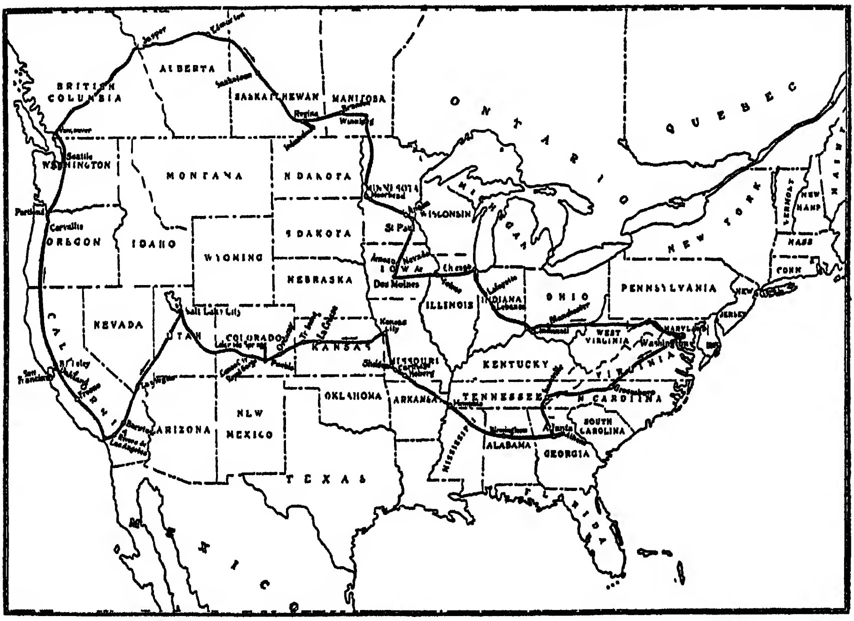


FIG. 1. MAP OF THE ROUTE OF THE TRANSCONTINENTAL EXCURSION
(Courtesy Baltimore & Ohio Railroad)

further the friendships formed at Washington and to give opportunity for discussions and exchange of ideas that had not been possible during the busy days of the Congress.

The excursion train which left Washington on the evening of June 22 carried a party of 206, approximately half of whom were foreign delegates, and the other half representatives of American agricultural colleges and experiment

stations, of the U. S. Department of Agriculture, and of business organizations. The excursion party also included 29 women for whom special programs were arranged at the different stops.

During the 30-day period of the excursion the train passed through 23 stations and 4 Canadian provinces. In addition to making 34 stops for the study of soil regions, the party visited 12 agricultural experiment stations and the plants of a number of manufacturing industries related to agriculture. The route of the excursion is shown on the map given in figure 1. Throughout the entire trip, the agricultural officials, chambers of commerce, boards of trade, and private business organizations coöperated in extending every possible courtesy to the delegates. In addition to the 12,000 miles covered by the train, the committees at various stops provided automobile transportation for local excursions which covered additional travel to the extent of about 1500 miles.

The executive committee takes this opportunity to express its appreciation of the hearty coöperation of the local committees and the officials of the several railroads over which the excursion train travelled.

A STUDY OF THE PROTOZOA OF SOME AMERICAN SOILS

H. SANDON[1]

Rutgers University[2]

Received for publication September 21, 1927

In 1916 Kopeloff, Lint and Coleman (7) concluded their excellent and exhaustive review of past work on soil protozoology with the remark that it was a science still in its infancy. Since then much has been done to place our knowledge of these organisms and of their activities in the soil on a firmer basis, but, in spite of this, considerable differences of opinion still exist on the fundamental question of their significance in the economy of the soil. On the one hand, data have been accumulating at Rothamsted demonstrating that protozoa occur in the local soils in considerably greater numbers than was formerly believed, and that they are capable of playing a significant rôle in soil processes (3, 4, 9). On the other hand, counts made by R. V. Allison (2) of protozoa in some samples of American soils gave very low figures, and caused him to admit that they "might be regarded, in a general way, as supporting the counter-protozoa theory." The samples he used, however, had been stored for some time before the counts were made and he therefore added that "until careful studies of freshly sampled soils are made . . . . all conclusions drawn in this connection must be regarded as distinctly tentative."

With a view to reconciling, if possible, these rather conflicting points of view, a detailed examination of various American soils was made, the primary object being to determine to what extent the protozoa in them are either numerically or qualitatively comparable with those found in English soils.

The greater part of the work was done at the New Jersey Experiment Station where attention was directed mainly to the experimental agronomy plots (table 1). Counts of protozoa were made by Cutler's dilution method (3, 11), and bacteria, actinomyces, and fungi were counted by the plate method using the media recommended by Waksman and Fred (12). The samples used were all composite ones from a series of 6-inch borings. In all the plots wide differ-

[1] Now in the department of general microbiology, Rothamsted Experimental Station. The work recorded in this paper was done under the auspices of the International Education Board. The author wishes to express his indebtedness to the Board and also to Dr. Lipman and the staff of the New Jersey Agricultural Experiment Station and especially to Dr. Waksman for much kindness and help. His cordial thanks are also due to Dr. Greaves and other members of the staff of the Utah State Agricultural Experiment Station for their hospitality to him while working at Logan.

[2] This paper is part of a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Rutgers University.

TABLE 1

Results of examination of soils from the Experiment Station Farm, New Brunswick, N. J.

SOIL	TREATMENT	DATE	CROP* YIELD	TOTAL N	pH	H_2O	BACTERIA	ACTINOMYCES	FUNGI	FLAGELLATES	AMOEBAE	CILIATES	NEMATODES
			pounds	*per cent*		*per cent*	*millions*	*millions*					
7A	No manure, unlimed†	September	3,881	0.074	5.3	8.0	2.8	0.8	89,000	121	165	0	0
7B	No manure, limed†	September	8,689	0.080	7.0	9.9	6.4	3.3	28,400	196	222	0	0
9B	Minerals $NaNO_3$ (16 pounds), limed†	October	18,599	0.074	6.8	11.0	4.7	2.7	12,184	770	938	25	0
5B	Complete minerals + cow manure (1600 pounds) annually, limed	October‡				11.3	6.6	3.3	17,344	719	1,010	15	0
		November				12.8	12.3	3.8	44,800	<115,000	28,770	<28,770	0
		January‡	19,033	0.128	6.9	.....	4.4	8.1	17,400	2,600	13,600	135	0
		March 2				16.6	4.2	1.7	28,800	2,600	44,000	110	Few
		March 25–28§						7.5	....	<222,000	125,000	<186	0
5A	Same as 5B, but unlimed	January‡					3.9	7.7	46,400	1,750	18,600	104	Few
		March 2	21,812	0.134	5.2	23.2	13.5	8.4	177,200	900	>220,000	160	0
		March 25-28§				17.5	....	5.4	....	17,700	46,600	172	0
Penn loam	Alfalfa	April§	......	.....	...	15.25	23.5	7.7	8,543	10,785	10,785	98	0
	Fallow after corn	April§	......	.....	...	16.9	36.5	10.4	58,013	4,795	81,495	263	Few

* Total dry matter 1918–1922.

† Average of 4.

‡ Average of 2.

§ Average of 3.

ences occurred in the numbers of all the groups of organisms at different times of the year similar to those found in the course of the Rothamsted counts of 1920–21 (3), where the changes have been shown to occur simultaneously in various parts of a field and therefore not to be due simply to sampling errors. Thus in plot 5B (receiving cow manure, and minerals annually, with occasional liming) the average of two counts made in October, 1925, was 700 flagellates, 1,000 amoebae, and 15 ciliates per gram, numbers which are slightly lower even than those obtained by Allison for the same soil. On the basis of these figures a series of dilutions was selected for making a count the next month. These were found to be totally inadequate, flagellates occurring in all the cultures, even those made from the highest dilutions. No estimate, therefore, could be made of their numbers except that they must have exceeded 115,000 per gram. The amoebae were about 28,770 and the number of ciliates, though the exact figures were uncertain, was even greater. At the same time the bacteria rose from 6.6 million to 12.3 million and the fungi from 17,300 to 44,800 whereas the actinomyces rose slightly from 3.3 to 3.8 million. The number of ciliates was most remarkable and was never again approached.

In view of the strange effects of the freezing of soil on its bacterial flora, which have been recorded from time to time, and the paucity of information as to the effect of frost on protozoal numbers, counts were made on this plot at intervals throughout the winter. The average of two counts made in January, 1926, at a time when the soil was frozen so hard that the sample had to be taken with a hammer and chisel, gave 2,600 flagellates, 13,600 amoebae, and 135 ciliates. All of these figures are considerably higher than those obtained in October. The number of fungi was practically unchanged (17,400), but that of the actinomyces was remarkable, being 8.1 millions per gram as compared with 4.4 million bacteria. This result is particularly unexpected since Lochhead (8) not only did not obtain any increase in the numbers of actinomyces in frozen soils at Ottawa, but showed further that their optimum temperature is higher than that of the majority of soil bacteria. It is possible therefore that the higher figures obtained in the present work are the result simply of greater fragmentation of the actinomyces and do not indicate any real increase in numbers. Waksman (10) gives no record of the numbers of actinomyces found in the course of his investigation of the seasonal changes in bacterial numbers in the New Jersey soils. Lochhead also recorded a slight depression in protozoal numbers during freezing, which again is contrary to what was found in the present investigation. Such differences may be due to the additional severity and length of the Canadian winter, but, in view of the wide margin of error in all counts of soil organisms, far more counts than have yet been made are required before we are justified in claiming finality for any conclusions on such matters.

On keeping one of these samples in the laboratory at room temperature for 3 days, big increases in numbers of all the organisms except the actinomyces occurred. Flagellates and amoebae both increased to more than 220,000 per

gram; ciliates to 2,280; bacteria to 15 million; and fungi to 46,400, whereas actinomyces fell to 5 million.

By the beginning of March the soil had thawed to a depth of a few inches and counts made of a sample of this thawed soil showed little change as compared with the completely frozen soil. This sample was afterwards dried in the laboratory for 24 hours at 32°C. and a second count then made, but even this treatment led to little alteration in protozoal numbers though the bacteria rose from 4.2 to 14.5 million and the actinomyces from 1.7 to 5.5 million.

Finally three counts were made at the end of March when the soil was completely thawed. The bacterial and fungal counts were unfortunately lost but all the groups of protozoa showed a big increase, the flagellates averaging something over 220,000; amoebae, 125,000; and the ciliates not fewer than 186 per gram.

These winter counts were paralleled with samples from the corresponding unlimed plot 5A with very similar results, except that the count made at the beginning of the thaw (March 2) yielded extraordinarily high numbers (>220,000) of amoebae.

Thus, so far as it is safe to draw conclusions from so few observations, it appears that severe frost does not diminish the protozoal population, and subsequent thawing acts as a stimulus to multiplication.

A few counts were made of other plots. Plots 7A (unlimed) and 7B (limed) which have received no manure or fertilizer since 1908 were very poor in protozoa and on the average of 4 counts the limed plot showed a slight advantage in numbers of protozoa when compared with the unlimed plot, corresponding to its greater bacterial flora. Plot 9B, receiving complete artificial fertilizers (nitrogen as $NaNO_3$) contained a fauna and flora differing very little from the corresponding plot 5B in which the nitrogen had been added in the form of farm-yard manure and in which consequently much organic matter was present. These counts were made in October and, as already mentioned, those from 5B proved exceptionally low; consequently it is not possible to say whether this close similarity would persist throughout the year.

With the exception of the counts made just after the thaw, all the figures obtained were considerably lower than those found in the corresponding plots at Rothamsted. This doubtless corresponds to the much lower bacterial figures. Samples taken of adjacent plots of a different type of soil (Penn loam) on the same farm, however, gave figures for both bacteria and protozoa of the same order as those found at Rothamsted.

In order to compare some soils where conditions differ more widely from those in England than do those in New Jersey, single counts were made of bacteria and protozoa in a number of soils from the neighborhood of the experiment station at Logan, Utah (table 2). In order to secure as many protozoal counts as possible within 6 weeks, an abbreviated series of dilutions was used, in which each soil suspension contained one-fourth instead of one-half the amount of soil in the preceding one. The number of cultures made was thus much reduced

at a sacrifice of accuracy, the significance of the result being only 1/5 (i.e. a count of 10,000 organisms indicating only that the actual number lies somewhere between 2,000 and 50,000).

The irrigated sugar beet plots of the experiment station farm (of which 4 were examined) yielded a fair number of protozoa. The plot receiving manure equivalent to 30 tons per acre annually, contained considerably more organisms than the unmanured plots, and though the plot receiving an even heavier dressing (40 tons) of manure showed slightly lower figures, the difference is not significant.

Two samples of dry farm soil were taken (one under wheat stubble and the other fallow). The moisture content was only about 3 per cent in each of these and the protozoa were apparently all encysted. Flagellates and ciliates were very few, but the amoebae reached several thousand per gram in each sample.

A number of samples were taken of alkaline soils both from the field and from pots. Numbers both of bacteria and of protozoa were low, and the amoebae were invariably more numerous than the flagellates. It seemed possible, however, that the organisms in such soils had become adapted to very abnormal conditions and that consequently the neutral nutrient agar used as culture medium for the counts was not suitable for their development. In three cases, therefore, a duplicate count was made using agar to which no nutrients or salts had been added but in which soil or soil extract from the same sample as that being counted was incorporated. In all three cases the counts obtained with this medium were very much greater than those obtained with the ordinary agar. The numbers obtained from such abnormal soils with ordinary agar, therefore, do not give a true account of the soil fauna, and even for more normal soils the soil agar is probably preferable, especially in view of the ease with which it can be prepared. François-Perey (6), working in France, also obtained higher counts with a soil extract medium than with a meat extract agar.

Thus it appears that some degree of protozoal activity occurs in all these soils. In the very dry soils activity apparently ceases, but doubtless is resumed after rain. In alkaline soils numbers are also much reduced, particularly where the principal salt is carbonate ("black alkali"). The numbers are, however, much greater than would be expected if the protozoa were incapable of any activity but were limited to cysts brought in by the wind. In view of the fact that in artificial media many of the soil protozoa can live at very high degrees of alkalinity it seems probable that a little activity persists in all these soils, at any rate after rain when the osmotic pressure is somewhat reduced and some amount of leaching has taken place from the surface.

The nitrogen content of most of these soils, however, was found to be exceptionally high (table 2). This suggests the presence of an amount of organic matter which would normally be expected to provide the nidus for a microflora and fauna far greater than that actually found. This is true not only of

TABLE 2

Results of examination of soils from Cache Valley, Utah

SOIL NUMBER	CROP AND TREATMENT	TOTAL N	SALTS	pH	WATER	BACTERIA	ACTINOMYCES	FLAGELLATES	AMOEBAE	CILIATES	NEMATODES
		per cent			*per cent*	*millions*	*millions*				
				Greenville Farm							
1	Beat, irrigated, no manure	0.16	Carbonates constitute about 45 per cent of all these soils	About 8.0	5.2	.....	1.0	899	7,193	28	Few
2	Beet, irrigated, no manure	0.14		7.5–8.0	6.4	.....	0.9	450	3,596	225	0
3	Beet irrigated, 30 tons manure	0.23		7.5–8.0	7.2	.....	1.7	14,380	28,770	114	0
4	Beet, irrigated, 40 tons manure	0.33		7.5–7.8	8.0	.....	3.5	7,193	7,193	225	0
				Dry wheat land							
Stubble	Wheat and fallow on alternate years	0.108	....	7.5–8.0	3.1	19.0	8.5	114	7,193	Few	0
Fallow		0.126	....	7.5	3.0	18.9	5.5	450 (25 cysts)	16,000 (All encysted)	38	0
				Alkaline field soils							
A1	Wheat	0.098	CO_3	7.5–8.0	3.2	8.5	2.1	225	14,380	56	0
A2	Wheat	0.114	CO_3	7.5–8.0	3.3	8.4	2.9	Few (7,193)*	28 (115,000)*	Few (Few)*	0
R	Pasture	0.33	CO_3	8.8–9.0	13.3	10.4	6.0	225 (1,798)*	1,798 (14,386)*	28 (450)*	0
B1	Pasture	0.05	CO_3 and Cl	About 9.0	7.2	4.9	0.1	71	57	28	0

B2	Pasture just being ploughed up	0.07	CO_3 and Cl	8.8–9.0	7.7	12.8	1.0	57 (57)*	900 (3,596)*	7 (57)*	0 (Few)*
Alkaline pot soils											
85	....	.....	Mainly Cl	8.8–9.0	.....	3.4	0.1	34	40	0	0
86	....	.....	Mainly Cl	About 8.0	.....	7.1	0.9	16	3,000	3.4	0
97	....	.....	Mainly SO_4	$\nless 8.8$	.....	2.5	0	12.5	225	3.4	Few
98	....	.....	Mainly SO_4	$\nless 8.8$	.....	2.0	0	22.4	225	6.8	0
104	....	.....	Mainly CO_3	$\nless 9.6$	.....	0.1	0	0	160	12.5	0
110	....	.....	Mainly CO_3	About 7.2	.....	3.9	0	7.5	12.5	0	0

* Counts made with soil extract agar.

the alkaline soils but also of the manured plots on Greenville Farm; consequently it appears probable that not only the salts, but other factors such as soil temperature and moisture, limit the microbiological development in this area.

The part played by the protozoa in the economy of the soil does not, however, depend only on the total number present but is probably considerably influenced also by the species which make up this total; for, scanty as is our knowledge of their physiology and nutrition, there is considerable evidence of the existence of wide differences in these respects not only between the three main classes (flagellates, rhizopods, and ciliates) but also between the different genera and species within these classes.

Thus the exceptionally high figures obtained in the November count of plot 5B at New Brunswick were due entirely to the great development of three species—the flagellate *Cercomonas* sp., a "limax" amoeba, and the ciliate *Colpoda steinii*—other forms being almost entirely absent. This doubtless points to very different conditions from those which occur in normal heavily manured soils in which large numbers of protozoa are associated with a rich variety of forms.

A valuable qualitative survey of the protozoa in New Jersey soils was published by Fellers and Allison in 1920 (5) of which the present results as to the nature of the organisms present in those soils are largely a confirmation.

On the whole, the fauna both of the New Brunswick and of the Utah soils resemble closely those of the Rothamsted soils. Unfavorable conditions seem to affect the flagellates more than the amoebae, since, although in soils where protozoa are abundant it is the flagellates which preponderate, among the soils examined in the present investigation it was found that, where the total population is small, the flagellates are generally exceeded by the amoebae.

The most interesting differences occurred in the amoebae. At the time of their investigation, Fellers and Allison found *Naegleria gruberi* (Schardinger) Wilson to be by far the most abundant of the soil amoebae. The same was true in the soils at Rothamsted in 1920–21, but more recently this species has been there almost completely replaced by another "limax" amoebae *Hartmanella hyalina* Alexeieff. Both at New Brunswick and at Logan, however, these forms were found to be outnumbered by others at present not fully identified. The most abundant species at New Brunswick were very similar in appearance and movements to *Hartmanella hyalina* though on the average slightly larger. On the addition of sterile water to a culture, however, flagellate forms are produced as in *Naegleria* but distinguished by the possession of only a single flagellum (pl. 1., figs. 1, 2). It accordingly belongs to the genus *Hyperamoeba* (see appendix).

One of the amoebae found commonly at Logan was at first mistaken for this, since both the active amoebic form and the cyst were indistinguishable. As all attempts to obtain a flagellate form failed, this species is provisionally referred to in table 3 as "sp. C."

TABLE 3

*Occurrence of various flagellates, rhizopods and ciliates in the soils tested**

Flagellata	
Cercomonas sp.	5A(9/9), 5B(13/13), 7A(5/5), 7B(5/5), 9B(2/2), P.a.(3/3), P.c.(3/3), 1, 2, 3, 4, D.f., A1, A2, R, 86
Cercobodo agilis Moroff	?5A(1/9)
Cercobodo vibrans Sandon	?5B(1/13), ?7A(1/5), 7B(1/5)
Helkesimastix faecicola Woodcock and Lapage	9B(1/2)
Monosiga ovata Kent	5B(2/13), P.a.(1/3), P.c.(1/3)
Phalansterium solitarium Sandon	5A(1/9), 5B(3/13), 7A(2/5), 7B(2/5), 9B(1/2), P.a.(1/3)
Bodo edax Klebs	7A(2/5), 7B(3/5)
Bodo saltans Ehrbg	5A(1/9), 5B(5/13), ?P.c.(1/3)
Bodo sp. (?)	5A(3/9), 5B(8/13), 7A(3/5), 7B(1/5), P.a.(3/3), P.c.(3/3), B2
Heteromita spp.	5A(7/9), 5B(7/13), 7A(5/5), 7B(4/5), 9B(2/2), P.a.(1/3), P.c.(3/3), 3, D.f., A1, A2, R, B1, B2, 85, 86, 97, 98, 110
Phyllomitus sp.	?R, ?B2
Spiromonas angusta (Duj)	5A(?2/4), 5B(?2/13), 7B(2/5)
Sainouron mikroteron Sandon	5A(1/9), 5B(6/13), 9B(2/2), P.a.(1/3), P.c.(2/3) 3, 4, R, B2
Allantion tachyploon Sandon	5A(5/9), 5B(7/13), 7A(1/5), P.c.(1/3), 1, 3, D.f., R, B1
Proleptomonas faecicola Woodcock	5A(4/9), 5B(7/13), 7B(1/5), 9B(1/2), P.c.(1/3)
Spongomonas sp.	5A(4/9), 5B(1/13), P.c.(1/3), 3, 4, D.f.
Tetramitus rostratus Perty	5B(1/13), P.c.(?1/3), ?98
Tetramitus spiralis Goodey	5B(1/13), 7A(2/5), 7B(3/5)
Oikomonas termo (Ehrbg) Martin	5A(9/9), 5B(10/13), 7A(1/5), 9B(1/2), P.a.(3/3), P.c. (3/3) 1, 2, 3, 4, D.f., A2, R, B2
Monas sp.	5A(1/9), R
Scytomonas pusilla Stein	5B(4/13), 7A(1/5), 7B(2/5), 9B(1/2), P.a.(1/3)
Anisonema minus Sandon	5A(1/9)
Allas diplophysa Sandon	5A(7/9), 5B(7/9), 9B(1/2), P.c.(2/3)
Dimastigella trypaniformis n. gen., n.sp.	5A(7/9), 5B(7/12), P.a.(3/3), P.c.(3/3), 3, 4
Unidentified spp.	1, 2, 3, 4(2 spp.), D.st., D.f.(2 spp.), A1(2 spp.), R (3 spp.), B2
Rhizopoda	
Hartmanella hyalina (Dangeard) Alexeieff	5A(8/9), 5B(12/13), 7A(5/5), 7B(5/5), 9B(2/2), P.a.(3/3), P.c.(3/3), 1, 2, 3, 4, R, B2, ?98
Naegleria gruberi (Schardinger) Wilson	5A(4/9), 5B(5/13), P.a.(3/3), P.c.(3/3), A2
Hyperamoeba sp.	5A(9/9), 5B(9/13), P.a.(3/3), P.c.(3/3)
Amoeba limax. sp. C	1, 2, 3, 4, D.st., D.f., A1, A2, R, B1, B2, 85, 86, 97, 98, 104, 110, (i.e., every Utah soil examined)
Amoeba limax. sp. D	1, 2, 3, 4, D.st. D.F., A1, A2, R, B2, 85, 86, 97, 98, 104, 110, (i.e., every Utah soil except B1)
Amoeba guttula Duj	5B(?1/13), 1
Amoeba verrucosa Ehrbg	5B(?2/13), ?3, 4, A1, R

TABLE 3—*continued*

Amoeba diploidea Hartmann and Nägler	5A(1/9), 5B(6/13), 7A(2/5), P.c.(2/3)
Amoeba striata Penard	?P.a.(1/3), ?P.c.(1/3)
Amoeba proteus Pallas (Leidy)	5B(2/13)
Amoeba albida Nägler	5B(2/13)
Amoeba "radiosa"	3, R
Amoeba sp.	5A(1/9), 5B(2/13), 7A(2/5)
Biomyxa vagans Leidy	5A(1/9), 5B(2/13), P.c.(1/3)
Arachnula impatiens Cienkowsky	2
Gephyramoeba delicatula Goodey	5B(1/13)
Nuclearia sp.	5A(1/9), 5B(4/13), P.a.(2/3), P.c.(2/3), 1, 3, 4, A1, R, B2
Actinophrys sp.	5B(2/13)
Difflugia globula (Ehrbg)	5B(1/13), R
Euglypha sp.	5B(2/13), 4
Trinema lineare Penard	5A(2/9), 5B(2/13)
Microgromia sp.	5B(5/13), P.a.(2/3), P.c.(3/3), 3
Lecythium hyalinum Hertwig and Lesser (= *Chlamydophrys stercoreum*)	5B(2/13), 9B(1/2), P.a.(1/3), P.c.(1/3)
Ciliata	
Holophrya sp.	5B(1/13), 1, 2, 3, 4, A2
Enchelys sp.	P.c.(1/3), A2, R
Prorodon sp.	R
Chilodon sp.	5B(1/13), P.c.(1/3)
Trochila sp.	?5A(1/9), 5B(1/13)
Glaucoma sp.	?5B(1/13)
Colpidium sp.	?5B(2/13), P.c.(2/3), ?R
Colpoda cucullus (O.F.M.)	5A(8/9), 5B(7/13), P.a.(1/3), P.c.(3/3), 4, D.f., ?A1, A2, R
Colpoda maupasii Enriques	4, D.f., ?R, ?B2
Colpoda steinii Maupas	5A(8/9), 5B(12/13), 7B(1/5), 9B(1/2), P.a.(3/3) P.c.(3/3), 2, 3, 4, D.f., A1, R, B1, 98
Cyclidium sp.	A2, R
Balantiophorus elongatus Schewiakoff	5A(6/9), 5B(11/13), P.a.(2/3), P.c.(3/3), 4
Balantiophorus minutus Schewiakoff	?5B(1/13), 4
Balantiophorus sp. (probably either *B. elongatus* or *B. minutus*)	1, 2, 3, D.st., A1, B1, 86, 97, 98, 104
Holotrichous sp. (unidentified)	5B(2/13)
Halteria sp.	R
Uroleptus sp.	5B(1/13), R
Onychodromus sp.	?A2, ?R
Gonostomum affine (Stein)	?1, R
Oxytricha sp.	5B(1/13)
Pleurotricha sp.	?5B(1/13)
Hypotrichous sp. (unidentified)	5A(4/9), 5B(3/13), 3, 4
Vorticella microstoma Ehrbg	5B(1/13), P.st.(1/3), A2, R

* The symbols following each name indicates the soils in which that organism was found. The symbols are the same as those used in the previous tables with the further abbreviations P.a. = Penn loam alfalfa, P.c. = Penn loam corn, D.st. = dry farm stubble, D.f. = dry farm fallow.

Where more than one sample was taken of any plot the number of samples in which the species was found is indicated by the fraction in parenthesis, thus *Monosiga ovata*, 5B(2/12) means that this organism was found in 2 out of 12 samples from plot 5B.

The other common species at Logan (referred to as "sp. D") also gave no flagellate form and had a smooth, thin-walled cyst like that of *Naegleria* but without any pores.

Among the flagellates the most striking feature was the relative scarcity of *Heteromita* sp. and *Oikomonas termo* (two of the most widely distributed and generally most numerous of all soil flagellates) in the New Brunswick soils. An interesting new flagellate *Dimastigamoeba trypaniformis* was found in both places (see appendix).

In brief, therefore, these investigations indicate that the protozoan fauna is very similar in all soils: the forms present are very similar even in widely differing soils and the numbers are roughly related to the bacterial numbers. In a soil in which the bacterial numbers (as counted by the plate method) are of the order of 5 millions per gram, the protozoa can usually be estimated in hundreds. Where the bacteria number 10 to 20 millions the protozoa can be reckoned in thousands or tens of thousands, whereas corresponding to bacterial counts of 40 or 50 millions, the protozoa may be expected to reach several hundred thousand per gram or even to exceed a million. These numbers are naturally very approximate but are probably minimal ones, for whatever errors there are in the dilution method of counting would tend to make the figure obtained too small rather than too large, and the surprising results obtained by using a soil medium in place of the ordinary nutrient agar in making the counts with the alkaline soils suggests that modifications in technique may reveal a larger population in all soils than has yet been found.

APPENDIX

Hyperamoeba sp. In appearance and movements the amoeba is very similar to *Hartmanella hyalina* Alexeieff, but on the average it is slightly larger than the latter species. The flagellate form (readily obtained by addition of fresh sterile water to a culture) is elongated or pear-shaped with the broader end behind (pl. 1. figs. 1, 2). The posterior end is very metabolic and coarsely vacuolated, whereas the anterior end is clear and contains an easily visible nucleus. There is a single contractile vacuole situated at the middle. The flagellum is inserted at the anterior end and is directed forward, the length being approximately equal to that of the body. It appears incapable of serving as a true swimming organ since the flagellate simply turns around slowly and jerkily on its long axis without moving forwards. Sometimes, however, it crawls along the surface of the microscope slide like a *Cercomonas* or *Mastigamoeba*. The cysts (pl. 1., fig. 3) resemble those of *Naegleria* rather than those of *Hartmanella* in possessing pores, but differ in having relatively thick and corrugated walls.

The only "limax" amoeba known which has a flagellate form with only a single flagellum is *Hyperamoeba flagellata* Alexeieff, recently found by Alexeiff (1) in horse manure from Finland. He gives no account of cyst-formation or of the cytology of the amoeba, and the present species was not examined under the conditions in which are obtained the characteristic forms by which alone *H. flagellata* can be identified. Consequently, pending a more detailed examination, the present species will be referred to simply as *Hyperamoeba* sp.

Dimastigella trypaniformis, nov. gen., nov. sp. This is a rather narrow, spindle-shaped organism closely resembling a *Trypanoplasma* in its general appearance and mode of motion. It is about 12μ long, possessing two flagella of which one is inserted at the anterior end and directed forwards, being about 2/5 to full body length, and the other being about twice as

long and directed backwards. This trailing flagellum adheres to the surface of the body and is occasionally thrown up for part or all of its length, forming the border of an "undulating membrane." The body is, however, generally circular in section and this thinning out to form a lateral membrane is not common. In swimming the active sinuous motion is very similar to that of a Trypanosome. A contractile vacuole is usually easily visible at the anterior end of the body.

On staining the flagellate, however, the "blepharoplast" or "kinetonucleus," which is generally regarded as diagnostic of the *Trypanosomaceae*, is found to be absent. Each flagellum ends in a minute granule, and when the contractile vacuole is dilated at the moment of fixing, it is seen to lie between the two granules, pushing them apart (pl. 1., figs. 4, 5). This species thus differs from the Cercomonads in which the basal granules are connected to the nuclear membrane. Werbitzky (13) has shown that under the influence of certain drugs the blepharoplast of *Trypanosoma brucei* is lost without the life or activities of the organisms being in any other respect noticeably affected. This raises some doubt, therefore, as to whether the structure may be regarded as absolutely diagnostic for the family, for it appears plausible that a structure which can be lost under artificial conditions may also be permanently lost in the course of natural evolution. For the present, therefore, it is proposed to include this flagellate in the family *Cryptobiaceae* of the *Protomastiginae* under the name of *Dimastigella trypaniformis* nov. gen., nov. sp., the genus being defined as free-living flagellates closely resembling the genus *Cryptobia* Leidy (*Trypanoplasma* Laveran et Mesnil) but possessing no blepharoplast.

The mode of nutrition has not been observed, but bacteria can often be observed lying within the plasma in stained preparations.

In older cultures, cysts are formed (pl. 1., fig. 6). These are spherical bodies, 4 to 5μ in diameter. The wall is noticeably smooth, possessing no pore, and appears as a single contour around the plasmic contents, which are very uniform, containing no refringent granules or vacuoles and completely filling the cyst. When stained, they show a simple vesicular nucleus often with a minute granule lying against its membrane. In this condition also the similarity to the corresponding resting stage of the Trypanosomes, as figured by several authors, is quite close.

Though many preparations have been stained and examined, division stages have not been observed. Excellent cultures of this species were ultimately obtained, but it appears to be rather sensitive to cultural conditions (i.e. possibly to the presence of certain other organisms) and its occurrence on the plates used for counting was so erratic that no estimate of its abundance could be obtained. As, however, it frequently occurred in cultures made from rather high dilutions of soil, it probably sometimes attains considerable numbers in the New Brunswick soils. Though it has not been recorded by any other investigators, it is probably rather widespread. Dr. F. C. Holmes told the author that he has observed it in soil cultures at the Boyce Thompson Institute. The author also found it once in Utah, and has observed it in England in cultures from some straw compost, and from several different soils, although always in small numbers.

REFERENCES

(1) ALEXEIEFF, A. 1924 Notes sur quelques protistes coprocoles. *Arch. Protistenk.* 50: 41–48.

(2) ALLISON, R. V. 1924 A note on the protozoan fauna of the soils of the United States. *Soil Sci.* 18: 339–352.

(3) CUTLER, D. W., CRUMP, L. M., AND SANDON, H. 1921 A quantitative investigation of the bacterial and protozoan population of the soil with an account of the protozoan fauna. *Phil. Trans. Roy. Soc. (London) Ser. B.* 211: 317–350.

(4) CUTLER, D. W., AND BAL, D. V. 1926 Influence of protozoa on the process of nitrogen fixation by *Azotobacter Chroococcum*. *Ann. Appl. Biol.* 13: 516–534.

(5) Fellers, C. R., and Allison, F. E. 1920 The protozoan fauna of the soils of New Jersey. *Soil Sci.* 9: 1–25.

(6) François-Perey, J. 1925 Influence du milieu du culture sur les numerations des protozoaires du sol. *Compt. Rend. Acad. Sci.* 180: 315–317.

(7) Koppeloff, N., Lint, H. C., and Coleman, D. A. 1916 A review of investigations in soil protozoa and soil sterilization. *Centbl. Bakt.* (II) 46: 28–74. Republished *Soil Sci.* (1917) 3: 197–289.

(8) Lochhead, A. G. 1924 Microbiological studies of frozen soil. *Trans. Roy. Soc. Canada* 18 (Sec. 5): 75–96.

(9) Sandon, H. 1927 The Composition and Distribution of the Protozoan Fauna of the Soil. Edinburgh.

(10) Waksman, S. A. 1916 Bacterial numbers in soils, at different depths, and in different seasons of the year. *Soil Sci.* 1: 363–380.

(11) Waksman, S. A. 1927 Methoden der mikrobiologischen Bodenforschung. Abderhalden's Handbuch der biologischen Arbeitsmethoden. Berlin.

(12) Waksman, S. A., and Fred, E. B. 1922 A tentative outline of the plate method for determining the number of microörganisms in the soil. *Soil Sci.* 14: 27, 28.

(13) Werbitzski, F. W. 1910 Ueber blepharoblastlose Trypanosomen. *Centbl. Bakt.* (I) 55: 303–315.

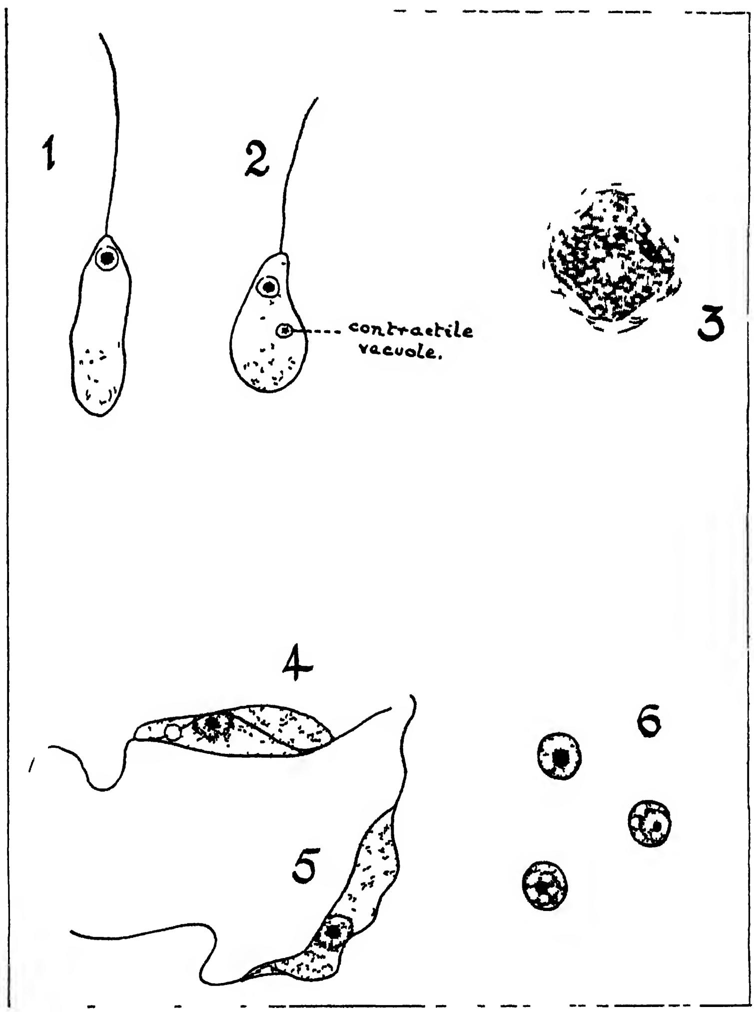
PLATE 1

Figs. 1 and 2. *Hyperamœba* sp. Flagellate Stage. (Freehand sketches from life.)

Fig. 3. *Hyperamœba* sp. Cyst. (From life.)

Figs. 4 and 5. *Dimastigella trypaniformis*. Active Form. (Stained with Heidenhain's haematoxylin.)

Fig. 6. *Dimastigella trypaniformis*. Cysts. (Stained with Heidenhain's haematoxylin.)


1
2
contractile
vacuole.
3
4
5
6

THE PRODUCTION OF PYRUVIC ACID BY CERTAIN NODULE BACTERIA OF THE LEGUMINOSAE[1]

J. A. ANDERSON, W. H. PETERSON, AND E. B. FRED

University of Wisconsin

Received for publication September 22, 1927

In spite of numerous investigations of the root nodule bacteria of legumes, little has been published regarding the products formed from carbohydrates by these microörganisms. A few investigators (20, 5, 18, 2), have noted a change in reaction and in some cases have recorded the titratable acid developed in the medium, but apparently no one has made a serious attempt to determine the nature of these acids. This paucity of data is partly explained by the fact that most of these bacteria produce less than 5.0 cc. of 0.1 N acid per 100 cc. of culture whereas others not only produce no acid but may even bring about an alkaline reaction in the medium. In this paper, data will be presented to show that certain of these bacteria produce pyruvic acid from various carbohydrates.

The occurrence of pyruvic acid in this type of fermentation is of special significance in that it furnishes one more link in the chain of evidence which has been adduced by Neuberg and his associates (14), Fernbach and Schoen (3), Mazé and Ruot (11, 12), Beijerinck and Folpmers (1), v. Grab (7), Quastel, Stephenson, and Whetham (16) and others regarding the important rôle played by this acid in the biochemical activities of plant and animal cells. As yet it cannot be said that pyruvic acid is an intermediate product in the decomposition of carbohydrates by all microörganisms but its isolation in an increasing number of instances makes such a possibility more and more probable. Another reason for believing that pyruvic acid may occur as an intermediate product more generally than has hitherto been reported is the fact that it is easily attacked by most microörganisms and hence does not accumulate in readily detectable quantities.

EXPERIMENTAL

Methods

The organism was grown in a solution of the following composition: K_2HPO_4, 0.5 gm.; $MgSO_4$, 0.2 gm.; NaCl, 0.2 gm.; KNO_3, 0.5 gm.; $CaSO_4$, 0.1 gm.;

[1] Published with the permission of the Director of the Wisconsin Agricultural Experiment Station.

From the Departments of Agricultural Bacteriology and Agricultural Chemistry.

Carbohydrate 5.0 to 10.0 gm.; Water, 1000 cc. To this was added 10 cc. of a yeast water extract (1 part yeast, 10 parts water) and the hydrogen-ion concentration was adjusted to pH 7.0. At the time of inoculation, sterilized $CaCO_3$ was added in excess.

Two strains of nodule bacteria from alfalfa, which had been studied in this laboratory for several years and which were known to be particularly high acid producers, were selected for this work. The purity of the inoculum and of the culture at the end of the fermentation was tested by transfers to litmus milk and potato slants. Cultures which showed any sign of contamination were discarded. In the first two experiments cultures were prepared by placing 1,000 cc. of the medium in 4-liter Erlenmeyer flasks, thus giving a shallow layer. In the later work, cultures of from 8 to 10 liters were prepared by growing them in 12-liter Florence flasks and aspirating sterilized air through the culture medium.

At the time of analysis, the cultures were filtered through paper pulp and the filtrate was evaporated to a convenient volume at a temperature of about 70°C. In the first two experiments the acids were divided into two portions: a volatile portion obtained by steam distillation, and a non-volatile portion obtained by extraction of the residue after the steam distillation, with ether in a Kutscher-Steudel apparatus. It was found later, however, that steam distillation destroyed a considerable part of the acids. Because of this loss of material, the procedure was modified in the later experiments. By converting the extracted acids into their barium salts, a partial separation was accomplished by means of alcohol. About one-fourth of the weight of these barium salts was insoluble in 80 per cent ethyl alcohol. This precipitate contained the barium salt of an acid which in the free state underwent partial decomposition on heating.

The crude gum produced by the bacteria was determined by precipitation with alcohol from the previously filtered and concentrated cultures. Since the calcium salts of some of the acids present are precipitated by alcohol, it was necessary first to acidify the culture residue before the addition of the alcohol. After the gum had been filtered off on a hardened filter, the filtrate was carefully neutralized, the alcohol removed by distillation under diminished pressure, and the acids were extracted by ether from the acidified residue as explained above.

Experiment 1

A preliminary experiment was run to determine the rate of fermentation and quantity of acid produced in a 1 per cent solution of glucose. Eight liters of shallow cultures were inoculated with culture 107. The unfermented glucose was determined from time to time. The data are summarized in table 1.

The results of Experiment 1 show that this organism ferments glucose slowly with the production of only small amounts of acids. The rate of sugar utilization was approximately constant throughout the 45 days of fermentation.

Experiment 2

Experiment 2 was conducted in a manner similar to experiment 1. Numbers 1, 2, 4, and 6 were one-liter cultures contained in 4-liter Erlenmeyer flasks. Number 3 was a 1½-liter culture contained in a 12-liter Florence flask. All cultures were of the same depth of liquid and were shaken thoroughly each day. The data are given in table 2. From this table it is seen that the yields of acid are somewhat higher with strain 100 than in the previous experiment where strain 107 was used.

TABLE 1

The rate of glucose fermentation and acid production by alfalfa culture 107

Calculated for 1000 cc. of culture

AGE	GLUCOSE FERMENTED*	SUGAR FERMENTED PER DAY	0 1 *N* ACID	
			Volatile	Non-volatile
days	*grams*	*grams*	*cc*	*cc.*
15	1 59	0 106	....	....
34	3 65	0 107	3 8	14.2
34	4 23	0 124	9 9	14 7
45	4 35	0 097	20 3	30.9
45	4 30	0 095	13 4	27 0

* Glucose present at start, 9.275 gm.

TABLE 2

The rate of glucose fermentation and acid production by alfalfa strain 100

Calculated for 1000 cc. of culture

FLASK NUMBER	AGE OF CULTURE	GLUCOSE FERMENTED*	0 1 *N* ACID	
			Volatile	Non-volatile
	days	*grams*	*cc*	*cc.*
1 and 6	18	1 10	8 9†	17.8†
3	32	4 68	7 0	37 3
2	39	5 66	16 5	54.5
4	41	6 00	24 4	39.7

* Glucose present at start 9.313 gm.

† Acids extracted by ether and steam distilled, 50.1 cc. Destroyed by distillation, 23.4 cc.

The instability of the acids found in the culture is illustrated in the case of flasks 1 and 6. Instead of subjecting the culture to steam distillation it was extracted with ether, a portion of the extract was titrated, and the remainder was then distilled with steam. Almost 50 per cent of the titratable acid was destroyed by this treatment. It is therefore impossible to say how much of the volatile acid given in tables 1 and 2 was formed during distillation and how much, if any, was produced by the bacteria.

Experiment 3

In this experiment the growth and acid production of the organisms on different sources of carbon were tested. In most cases 8 to 10 liters of culture were grown in a single flask at room temperature and aerated during the fermentation. The analytical data are given in table 3.

Except in the case of the lactose culture the destruction of sugar was almost complete. In the case of lactose an addition of 5 gm. of sugar per liter was made 12 days after inoculation. Most of this remained unfermented at the

TABLE 3

Production of acid from sugars and mannitol by alfalfa culture 107

Calculated for 1000 cc. of culture

FLASK NUMBER	TREATMENT	AGE	COMPOUND FERMENTED		TITRATABLE ACID (0 1 N)	GUM
			Kind	Weight		
		days		*grams*	*cc.*	*grams*
1	Aerated	19	Mannitol	5 00	19.5	1 30
2	Aerated	16	Sucrose	5 00	33 7	1 11
3	Aerated	39	Lactose	5 20	40 3	1 86
4	Not aerated	120	Xylose	4 86	20 0	....

TABLE 4

Properties of the acid solution obtained from mannitol, glucose, and sucrose cultures

REAGENT TESTED WITH	RESULT
Ammoniacal silver nitrate	Rapidly reduced at room temperature.
Fehling's solution	Reduction on warming.
Sodium nitro-prusside	Blue green coloration, yellow on heating.
B-napthol test	Reddish coloration.
Ferric chloride solution	Reddish brown coloration, no precipitation.
Phenylhydrazine and para-nitro-phenylhydrazine	Hydrazone formed at room temperature.
Iodine + NaOH	Iodoform produced at room temperature.
Schiff's reagent for aldehydes	No reaction.
Uffelman's reaction	Blue-green coloration.

end of the experiment but a large part of it had been converted into glucose and galactose. Determinations of reducing sugar before and after hydrolysis showed that about 60 per cent of the unfermented lactose had been hydrolyzed by the bacteria.

The most rapid development of acid took place in the case of sucrose. Mannitol is conspicuous by the fact that although approximately the same weight of material was fermented as in the case of sucrose and lactose, much less acid was formed. The yield of acid per gram of xylose consumed was about the same as for mannitol. It is probable, however, that during the long period of fermentation much of the acid produced was destroyed.

The existence of pyruvic acid in the culture

After removal of the gum the culture was neutralized, concentrated, acidified, and the acids extracted with ether in a continuous extractor. The concentrated solutions of the acids obtained on distilling off the ether were usually light yellow or brownish. This color still persisted when the acids were converted into their barium salts and could not be removed by extracting these salts with ether. Although treatment with bone black reduced the color of an aqueous solution of the salt, a considerable loss of material resulted.

When the ether was being removed from the extracted acids a small amount of a white fat-like substance soluble in ether and insoluble in water deposited on the sides of the flask. It was removed with ether and on evaporation of the ether crystallized in beautiful white needles. Owing to the small quantity of material obtained, the nature of this product has not been determined.

As already explained the free acids could not be subjected to a steam distillation without destroying some of the acid. With such evidence of instability, tests were made for the presence of aldehyde and ketone groups. The results of the tests are summarized in table 4. The same results were obtained from all of the cultures, indicating that the carbohydrate fermented is not responsible for the kind of product formed.

Although most of these tests are general for ketones and aldehydes, the color changes produced when testing with sodium nitroprusside and ammonia are stated by Simon (17) to be given only by pyruvic acid and acetophenone. These color changes are from blue, with various shades of blue-green in dilute solutions, to orange on heating, and fading entirely on boiling.

That the material yields no coloration with Schiff's aldehyde reagent may be regarded as evidence that a ketone group is responsible for the reactions listed. Meyer (13) states that it is not certain whether pure ketone solutions are capable of producing the typical violet-pink coloration with this reagent. Failure to obtain a precipitate with either ferric chloride or silver nitrate, indicated the absence of a number of acids, especially dibasic acids. Pyruvic acid in dilute solution produces a reddish brown coloration with ferric chloride and gives color reactions with Uffelman's reagent similar to those observed.

Para-Nitrophenylhydrazine derivative of pyruvic acid

Very small quantities of a para-nitrophenylhydrazine derivative were obtained from the acids extracted from all large cultures. It appeared to be identical in crystalline structure and melting point with the para-nitrophenylhydrazone of pyruvic acid. The melting point of this hydrazone was found to be between 218° and 220°C. Fernbach and Schoen (3), who were the first to isolate pyruvic acid from a natural source, give the melting point of their para-nitrophenylhydrazone as 219° to 220°C. Quastel (15), who obtained pyruvic acid by the fermentation of fumaric acid, gives the melting point of his compound as 219°C., and Hyde (8), who worked with synthetic pyruvic acid, states

the melting point of the hydrazone in question to be 219° to 220°C. Considerable difficulty was met with in the preparation of para-nitrophenylhydrazine derivatives. Fernbach and Schoen, and Quastel also reported this same difficulty. The former authors stated that this was probably due to condensation products of pyruvic acid, such as have been described by Wolff (19) and de Jong (9). Such condensations are readily brought about by several manipulations. We have found that a water solution of the barium salt of pyruvic acid is so altered by evaporating to dryness at 38°C. or by precipitating with ethyl alcohol that it no longer reacts with para-nitrophenylhydrazine.

Difficulty was experienced in purifying these hydrazones by recrystallization from methyl and ethyl alcohol. The material usually formed small amorphous globules, not unlike the oily residues sometimes obtained by the decomposition of benzene derivatives. It was later found that these globules slowly crystallized into burrs of needles on standing, and that the para-nitrophenylhydrazone of pyruvic acid may behave in an entirely analogous manner.

The iodoform reaction for pyruvic acid

As indicated in table 4, iodoform was rapidly produced in the cold by the acid in the presence of iodine and either sodium or potassium hydroxides. A rapid production of iodoform without heating is characteristic of the simpler ketones or ketonic acids such as acetone and pyruvic acid.

The acids obtained by the fermentation of sucrose in experiment 3 were analyzed for pyruvic acid according to Goodwin's (6) modification of Messinger's iodoform method. These titrations indicated the presence of 0.1153 gm. of pyruvic acid, assuming the reduction to be due to pyruvic acid. The titratable acidity or the portion taken for this analysis was 232.5 cc. of 0.1 *N* acid. Evidently a large part of the acids failed to produce iodoform. This may have been due to the formation of condensation products of pyruvic acid or it may be that part of the titratable acids consisted of acids other than pyruvic. That the reduction was not due to acetone or acetoacetic acid was proved by quantitative determinations for these compounds according to the Folin (4) method. The back titrations for the sample and for the control were almost exactly the same.

Barium salt of pyruvic acid and its condensation product

The mixture of acids extracted by means of ether from the cultures was neutralized with barium hydroxide. This solution was evaporated to a small volume and absolute ethyl alcohol was then added from time to time until a precipitate commenced to form. The last traces of water were thus removed by the evaporation of the alcohol. In this manner a friable brown mass of barium salts was obtained; 202.6 cc. of 0.1 *N* acids yielding 3.2558 gm. of salts dried at 105°C. If the acid solution consisted entirely of pure pyruvic the weight of the salt obtained should have been 3.1544 gm.

It was found that a portion of this mixture of barium salts was insoluble in

80 per cent ethyl alcohol. When 2.3002 gm. of salts from the large lactose culture was treated in this manner, 0.6543 gm. was found to be insoluble. It is improbable, however, that complete precipitation of the barium pyruvate was obtained. The alcohol-insoluble barium salt appeared homogeneous and free from impurities. After being filtered through hardened filted paper, the precipitate apparently took up moisture on standing, and became sticky and dark. When dried immediately, a white or grayish product was obtained. The barium salt reduced ammoniacal silver nitrate, gave a purple color with sodium nitroprusside and ammonia, and reacted at room temperature with iodine and sodium hydroxide to give iodoform. With para-nitrophenylhydrazine only a small amount of precipitate was formed. When the precipitate was recrystallized, it formed hydrazone-like needles, but a considerable quantity of resinous impurity was also present. Barium and calcium pyruvates, which had been precipitated from water solution by ethyl alcohol, likewise failed to give hydrazones with para-nitrophenylhydrazine. The hydrazine also failed to react with solutions of the pyruvates which had been evaporated to dryness at 38°C. Wolff and de Jong have shown that pyruvic acid readily forms condensation products at room temperature, and apparently the barium and calcium salts likewise readily undergo chemical changes. It is probable that the manipulation incident to the separation of the pyruvate from the fermented medium caused the main part of the salt to pass over into a compound which no longer reacted with the hydrazine.

TABLE 5

Elementary composition of the alcohol-insoluble barium salt

ELEMENT	PREPARATION NO. 1	PREPARATION NO. 2
Barium:		
Weight of sample.......... *gm.*	0.1092	0.0941
Weight of Ba SO_4.......... *gm.*	0.0827	0.0712
Ba.......... *per cent*	44.5000	44.4200
Ba in Ba $C_6H_6O_6$.......... *per cent*	44.1100	44.1100
Carbon:		
Weight of sample.......... *mgm.*	10.731	15.426
Weight of CO_2.......... *mgm.*	9.230*	11.275*
C.......... *per cent*	23.460	23.300
C in Ba $C_6H_6O_6$.......... *per cent*	23.120	23.120
Hydrogen:		
Weight of sample.......... *mgm.*	10.731	15.426
Weight of H_2O.......... *mgm.*	1.969	3.162
H.......... *per cent*	2.050	2.290
H in Ba $C_6H_6O_6$.......... *per cent*	1.940	1.940

* Corrected for CO_2 in the Ba CO_3 formed by combustion.

The alcohol-insoluble salt was dried in a vacuum over P_2O_5 and analyzed for barium, carbon, and hydrogen.[2] The data are given in table 5 and agree well with that required for $BaC_6H_6O_6$. Whether this is to be regarded as barium pyruvate or the barium salt of some condensation product such as de Jong's (9) α keto γ-oxybutene α, γ-dicarbonic acid, cannot be determined on the basis of the present data. Both of these compounds have the molecular formula $BaC_6H_6O_6$.

The colorimetric tests, the hydrazone with para-nitrophenylhydrazine, the iodoform reaction, and lastly, the elementary analysis, all lead to the conclusion that pyruvic acid is a normal product in the fermentation of carbohydrates by certain root-nodule bacteria.

SUMMARY

Xylose, glucose, sucrose, lactose, and mannitol were fermented by two strains of root nodule bacteria from alfalfa. The fermentations proceeded slowly and resulted in the formation of small amounts of acids, equivalent to approximately 5.5 per cent of the weight of the sugar fermented in the case of sucrose, and to 7.3 per cent in the case of lactose. Qualitative and quantitative determinations demonstrated the presence of pyruvic acid.

REFERENCES

(1) BEIJERINCK, M. W., AND FOLPMERS, T. 1916 The formation of pyruvic acid from malic acid by microörganisms. *Proc. K. Akad. Wetensch. Amsterdam* 18: 1198–2000.

(2) BIALOSUKNIA, W., AND KLOTT, C. 1926 Untersuchungen über Bacterium radicicola. *Ber. Gesamte Physiol. u. Exp. Pharmakol.* 29: 141–142.

(3) FERNBACH, A., AND SCHOEN, M. 1914 Nouvelles observations sur la production de l'acide pyruvic par la levure. *Compt. Rend. Acad. Sci.* 158: 1719-1722.

(4) FOLIN, O. 1907 On the separate determination of acetone and diacetic acid in diabetic urines. *Jour. Biol. Chem.* 3: 177–182.

(5) FRED, E. B. 1911–1912 A physiological study of the legume bacteria. Va. Agri. Exp. Sta., Ann. Rpt. *1912*: 145–173.

(6) GOODWIN, L. F. 1920 The analysis of acetone by Messinger's method. *Jour. Amer. Chem. Soc.* 42: 39–45.

(7) v. GRAB, M. 1921 Brenztraubensäure als Zwischenprodukt der alkoholischen Zuckerspaltung. *Biochem. Ztschr.* 123: 69–89.

(8) HYDE, E. 1899 Zur Kenntniss des p.-nitrophenylhydrazins. *Ber. Deut. Chem. Gesell.* 32: 1810–1818.

(9) DE JONG, A. W. K. 1901 L'Action de l'acide chlorhydique sur l'acide pyruvique. *Rec. Trav. Chim. Pays-Bas*, 20: 81–101.

(10) MAZÉ, P. 1918 L'Oxydation de L'Acide Lactique par le Bacteries avec Formation D'Acide Pyruvic et de Composes Cetonique. *Compt. Rend. Soc. Biol.* 81: 1150–1152.

(11) MAZÉ, P., AND RUOT, M. 1916 La production de l'acide pyruvic par l'oxydation de l'acide lactique. *Compt. Rend. Soc. Biol.* 79: 706–710.

---

[2] The authors are indebted to Mr. L. T. Hallett for assistance in making the micro combustions for carbon and hydrogen.

(12) Mazé, P., and Ruot, M. 1917 Recherches sur l'assimilation de l'acide lactique par les levures et sur la production l'acide pyruvique par les Oidiums. *Compt. Rend. Soc. Biol.* 80: 336–339.

(13) Meyer, H. 1922 Lehrbuch der Organisch-Chemischen Methodik I, ed. 4: 826. Berlin.

(14) Neuberg, C. 1924 Oppenheimer's Handbuch der Biochemie des Menschen und der Tiere, ed. 2: 442–483. Berlin.

(15) Quastel, J. H. 1924 On the fermentation of the unsaturated dicarboxylic acids. *Biochem. Jour.* 18: 365–380.

(16) Quastel, J. H., Stephenson, M., and Whetham, M. D. 1925 Some reactions of resting bacteria in relation to anaerobic growth. *Biochem. Jour.* 19: 304–317.

(17) Simon, L. 1897 Sur deux reactions colorées de l'acide pyruvique. *Compt. Rend. Acad. Sci.* 125: 534–536.

(18) Stevens, J. W. 1925 A study of various strains of *Bacillus radicicola* from nodules of alfalfa and sweet clover. *Soil Sci.* 20: 45–62.

(19) Wolff, L. 1901 Ueber ein neues Condensationsproduct der Brenztraubersäure. *Liebigs Ann. Chem.* 317: 1–26.

(20) Zipfel, H. 1911 Beiträge zur Morphologie und Biologie der Knöllchenbakterien der Leguminosen. *Centbl. Bakt.* (II) 32: 97–137.

THE pH VALUE OF SOME TEXAS SOILS AND ITS RELATION TO THE INCIDENCE OF CERTAIN WOODY PLANT SPECIES

ANTON H. BERKMAN

University of Texas

Received for publication September 6, 1927

In recent years great interest has been exhibited by ecologists in the H-ion concentration of soils and its relation to the natural distribution of plants. This interest coupled with the presence of a very favorable field for a study of this phase of ecology and with the apparent lack of such work in Texas, prompted the selection of this particular problem for investigation.

From a careful survey of literature treating of lime requirement and soil acidity, it is evident that the present problem of H-ion concentration and its relation to natural plant distribution is simply an outgrowth of the old problem of soil acidity and its relation to crop plants. Hence no attempt will be made here to review such literature (10, 19, 21, 22, 27, 29, 30, 32). The more recent problem, however, calls for a brief review.

Moore and Taylor (19) in their observation on a marine bog, found that 25 per cent of the components of the vegetation in the bog proper were of arctic alpine species. The pH value of the soil in this case ranged from 4.5 to 4.0. On a rock ledge at this same place, the pH value of the soil was 5.0, and only 6.3 per cent of the plants here were of arctic alpine species. None of these species occurred in the surrounding timber where the reaction of the soil was 6.0 Salisbury(25) observed that acid-loving plants were more frequent on ground where leaching was rapid, and that the valleys where alkaline substances collected after being leached from higher ground contained vegetation usually found in alkaline soils. Reed and Klugh (24), in their work on two pools located near each other, one a granite, and the other a limestone pool, showed that each one had its own characteristic biota. The pH of the water in the granite pool was 6.2 to 6.8, whereas that of the limestone pool was 7.6 to 9.2. Salisbury (26), calls attention to the fact that although *Psamana arenaria* and *Pteridium aquilinium* occur over a large pH range, the greatest frequency is at a definite pH value. The former occurs most frequently in the neighborhood of pH 7.1, whereas the latter seems to have an affinity for a reaction of about 5.5. Kelly (15) studied five different soil types, and concluded that soil acidity is one of the ecological factors in plant growth. A study of the distribution of species around salt marshes led Wherry (33) to a similar conclusion. Incidentally, in a study of the oak-hornbeam woods of Hertfordshire, England, Salisbury (24) observed that *Holcus lanatus*, *Cnicus palustris*, and *Anthantum odoratum*, all acid-loving species, invaded the coppiced areas. Analysis showed that these soils were much more acid than those from the uncoppiced woods.

Kurz (16) and Geisler (8), on the other hand, do not consider the H-ion concentration of much importance in the distribution of plants. Kurz seems to believe that the soil texture and composition, and not the soil reaction, is the more important factor of the two. Geisler, although stating that there is nothing in the results obtained to indicate that soil reaction is responsible for distribution, shows in the tables listed that certain species such as *Fagus grandiflora*, *Quercus palustris*, and many grasses, as a rule, occur only in acid reactions.

The laboratory from which the present investigation has been conducted is ideally located for the study of different types of soils and vegetation. Limestone soils from different formations of both the upper (Gulf series) and lower (Comanchean) Cretaceous periods are easily reached within an hour's travel from Austin. These soils, although of limestone origin, support different types of plant growth. Sandy soils, represented by the terraces of the Colorado River or of its ancestors are also abundant. These terraces, made up of sand and flint nodules from the Cretaceous (6), lie back of the river for a variable distance, sometimes being several miles wide. Beyond the limits of the Cretaceous they overlie the other geologic formations across which the Colorado has cut its present channel.

The Bastrop region, especially, unique in the field of ecology, affords a source of material unparalleled in any part of the state. The region is characterized by a "pine island" (area of about 40 sq. mi.), surrounded by oak-hickory forest growing upon sandy soil similar in texture and appearance to that which supports pine, thus offering an opportunity to study the H-ion concentration in sandy soils which have, apparently, the same texture, and yet support two widely different types of vegetation under the same climatic conditions. Hence, most of the work in the present investigation has been confined to this region.

The scope of the territory covered, and the limited time led the writer to confine the investigation to certain woody plants, as will be shown in the tables.

METHODS

The pH values of the soil extracts were determined by the colorimetric method. This method, although found in various modifications, is the most convenient, and is recommended as being sufficiently accurate for soil work (1, 32, 15, 16, 10, 4, 9). The one used in this laboratory is that of Barnett and Chapman.[1]

Most of the soil samples were taken at a depth of 6 inches. A few were collected at 4- and 12-inch depths. All of these samples, according to Emerson (7) are surface samples. In some cases, especially in ravines and road cuts, profiles of the soil, ranging from about 2 to 15 feet, were exposed. Three samples, each from a different area, were collected from such exposures at depths of 4, 6, and 10 feet, respectively.

The samples were carefully removed from the ground and placed in wide-mouth pint bottles, previously cleaned and rinsed with neutral water. Determinations of pH, as a rule, were made within 48 hours of collection. Samples which had not been tested at the end of 72 hours were discarded.

The soil extract was prepared according to methods used by Pierre (21), except that turbidity was removed in some cases by filtration aided by carbon

[1] Published in the Manual of Methods for Pure Culture Study of Bacteria, a manual prepared by the Committee on Bacteriological Technic of the Society of American Bacteriologists.

black. The lamp black, after having been washed to neutrality with neutral water, was added to the turbid solution and the mixture shaken vigorously for a few minutes. Upon filtration, a fairly clear solution was obtained. Before making use of this substance as an aid in filtration, several solutions that could be cleared by simple filtration were subjected to the treatment in order to test its effect upon pH. The results are given in table 1 below.

TABLE 1

Effect of lamp-black treatment on reaction of solutions

NUMBER	BEFORE TREATMENT WITH LAMP BLACK	AFTER TREATMENT WITH LAMP BLACK
	pH	*pH*
1	7.9	7.9
2	7.3	7.3
3	6.7	6 7
4	6.9	6.9
5	6.9	6 7

TABLE 2

Pinus taeda, dominant; Q. stellata and Q. Marylandica, lightly scattered

NUMBER	DEPTH	pH	KIND OF SOIL	SOURCE
1	4 inches	6.1	White sand	Under mat of pine needles
2	12 inches	6.7	White sand	Clear ground
3	6 inches	6.7	Yellow sand	Clear ground
4	6 inches	6.7	White sand	Clear ground
5	6 inches	6.7	White sand	Clear ground
6	6 inches	6.7	Yellow sand and gravel	Clear ground
7	6 inches	6.7	White sand	Clear ground
8	4 feet	6.1	Bluish clay and sand	In bank of ravine
9	4 inches	5.0	Sandy bog soil	Below artificial lake
10	6 inches	5.0	Sandy bog soil	Below artificial lake
11	6 inches	5.2	Red sand	In bed of ravine
12	6 inches	6.5	White sand	Clear ground, but fire swept
13	6 inches	5.0	White sand	Ground covered with pine needles
14	6 inches	7.3	Yellow sand and gravel	Near stream-slopes on both sides
15	6 feet	4.6	Bluish sand and clay	In bank of ravine
16	6 inches	6.1	Sand, gravel, and ferruginous rock	Knoll (mostly *Q. stellata* and *Q. Marylandica*) surrounded by pines
17	6 inches	6.7	Yellow sand and gravel	Clear ground

SOURCES OF SAMPLES

The samples from the pine timber were collected over an area that can be described as a belt about one mile in width and six miles in length, running

from the southern to the northern border of the area. Those from the oak-hickory association in the Bastrop region were taken at different places in a transection running from the postoak-pine contact into the postoak timber for a distance of about two miles north. Several samples were secured from postoak-blackjack associations outside of the Bastrop region. All the other samples were chosen from limestone soils where each area is characterized by a certain dominant species or by mixtures as is indicated in tables 4 and 5.

TABLE 3

Quercus stellata and Q. Marylandica, dominant

NUMBER	DEPTH	pH	KIND OF SOIL	SOURCE
1	6 inches	6.5	White sand	Clear ground
2	4 inches	6.5	White sand	Clear ground
3	4 inches	5.0	Yellowish clay and sand	In ravine bed—ravine having cut down about 3 feet
4	6 inches	4.8	Yellowish clay and sand	Same place, except a few yards from No. 3
5	6 inches	6 5	White sand	Clear ground
6	6 inches	5 0	Semi-decomposed ferruginous rock	On knoll (postoak-blackjack) surrounded by pine timber—few pines on knoll
7	4 inches	6.5	White sand	Clear ground
8	6 inches	6.5	White sand	Clear ground
9	4 inches	7.3	Yellow sand	Near creek bank
10	10 feet	6.3	White and yellow sand with small amount of clay	Road cut in hill
11	6 inches	6.5	Sand and fine gravel	Clear ground
12	4 feet	6.1	Yellow clay and sand	Ravine bed
13	6 inches	6 5	Sand and gravel	Clear ground
14	6 inches	6.5	White sand	Clear ground
15	18 inches	6.9	White sand	Same place as No. 14
16	6 inches	6.5	Sand and gravel	Clear ground
17	6 inches	6.1	Sand, fine gravel, and ferruginous rock	Clear ground on top of hill (pine area)
18	6 inches	6.5	White sand	Clear ground (Refugio, Texas)
19	6 inches	6.5	White sand	Clear ground (Victoria, Texas)
20	6 inches	6.5	White sand	Clear ground (Victoria, Texas)
21	6 inches	6.5	Sand and gravel	Clear ground (Ledbetter, Texas)
22	6 inches	6.7	Sand and gravel	Clear ground (Austin, Texas) on slope near drainage
23	6 inches	6.5	Sand and gravel	Clear ground (Austin, Texas)

It is evident that the distribution of the dominant species in the two areas represented by samples 1 to 17 in the tables 2 and 3, can not be explained on the basis of climatic factors, since both areas are exposed to the same rainfall and temperature.

This condition leaves but one other choice for explanation, namely, soil

factors. Among these, topography and soil texture, like climatic conditions, must be excluded, because both areas are characterized by the same soil mantle (river terrace material ranging in depth from about 8 inches to 2 feet), and practically the same topographic features. It is therefore of considerable interest to observe that all the surface samples taken from clear ground in the area represented by table 2, show a pH value of 6.7, whereas those under the same classification in table 3 have a pH of 6.5, thus indicating that the soil in the pine timber is characterized by a slightly lower H-ion concentration than that from the oak-hickory association.

The high concentrations found in samples 1 and 13 of table 2 can be accounted for by the fact that the samples were collected under heavy mats of decomposing pine leaves. The pine needles are rich in organic content and hence, on decomposing under conditions lacking proper aeration, furnish the surface soil with acids that give rise to temporary variations in the pH value. In this connection, no. 12 becomes of interest, since it was collected in a place similar to those of 1 and 13 with the exception that the mat had been destroyed by a recent fire, thus permitting proper aeration and also adding ash to the surface layer of soil. Samples 9 and 10 in table 2 conform to bog conditions (19). Numbers 8, 11, and 15 in this table constitute another group coming under a single category. Number 11, although listed as a surface sample, was collected in a ravine about 4 feet deep. These three samples are of no importance here except that they furnish data to show that the subsurface soil has a high H-ion concentration. The alkalinity represented by no. 14 is undoubtedly due to leached alkaline substances from the steep slopes near by. Salisbury (25) found similar conditions. Sample 16 presents another interesting condition. This sample was taken on a knoll covered with postoaks and blackjacks accompanied by a few pines. The surface here was characterized by sand, gravel, and fairly large boulders of ferruginous rock (iron clay). Geologically, this rock belongs to the Mt. Selman formation which will be discussed later. A sample from this iron clay, on being ground and treated as a soil sample, showed a pH of 5.2. Other examples of such knolls are represented by samples 6 and 17 in table 3, the pH value being the same in samples 16 (table 2) and 17 (table 3). Sample 6 in table 3 gave a reaction value of 5.0. Excluding the soil factors, the writer can give no reasons why these knolls should not be covered with a stand of pine, since all three places are surrounded by a good growth of pine timber.

Samples 3, 4, 10 and 12 in table 3 came under the same classification as 8, 11, and 15 in table 2; that is, they must all be considered as subsurface samples. Likewise, the alkalinity represented by the pH value in no. 9 (table 3) is accounted for in the same way as that of no. 14 in table 2. Sample 15 in table 3 was taken at a depth of 18 inches in the same place as no. 14. The difference between the two was 0.4 pH. Such a difference is in agreement with Salisbury's (25) results. He found different pH values at depth of 3, 6, 18, 24 and 48 inches respectively.

Samples 18 to 23, as is indicated in table 3, were collected from different localities outside of the Bastrop region. The surface soil, in each case, was practically of the same type as that described for the Bastrop area. Only one of these six samples, namely no. 22, registered a lower H-ion concentration than those from the Bastrop area. No other explanation can be given for this difference than the fact that the sample was collected near the edge of a ditch, thus coming under the same classification as 14 in table 2 and 9 in table 3.

The question may now be raised as to why the surface soil in the pine area should have a different pH value from that in the oak-hickory association. No

TABLE 4

Brown limestone soil—Quercus stellata, Quercus Texana, Sabina sabinoides (Ulmus crassifolia and Quercus Virginiana in ravines)

NUMBER	DEPTH	pH	SOURCE
	inches		
1	6	6.9	Slope
2	6	6.9	Slope
3	6	6.9	Slope
4	6	6.9	Slope
5	6	7.1	Near ravine—mainly live oaks and elms
6	6	7.5	In ravine—mainly live oaks and elms
7	6	6.7	Slope—young *Q. stellata*

TABLE 5

Brown limestone soil—Ulmus crassifolia, Quercus Virginiana, Quercus Texana, and Sabina sabinoides

NUMBER	DEPTH	pH	SOURCE
	inches		
1	6	7.5	Clear level ground
2	6	7.6	Clear level ground
3	6	7.6	Clear level ground
4	6	7.2	Old abandoned field
5	6	7.6	Clear level ground
6	6	7.6	Clear level ground

definite answer can be given to such a question at present. The writer, however, will venture to suggest a tentative and rather general explanation.

Basing our knowledge of the geology of the region on Deussen's report (5) and a manuscript at hand (6), we know that the substructure underlying the surface soil is not the same in each area. The main pine timber is practically limited to that portion of the soil mantle which rests on the Mt. Selman soil, whereas the oak-hickory association is supported by the Carrizo formation. These two formations differ lithologically, the Mt. Selman being rich in ferruginous material and red sandy clays, whereas the Carrizo formation is char-

acterized by crystalline sandstones, clays, and sand. Apparently, then, the chemical composition of the two is different. On such an assumption, we can expect that the mineral salts and acids in solution, rising to the upper layers by capillarity, will be of a different nature in each formation, thus giving a different pH value to the surface soil of each area.

Reaction values and their selective influence on the species named from the limestone soils are represented by tables 4 and 5. The surface mantle described in tables 4 and 5 is composed of practically the same kind of material; namely, brown, sandy, limestone soil interrupted by small fragments and

TABLE 6

Grayish limestone soil—Sabina sabinoides, dominant Quercus Virginiana and Q. Texana occurring incidentally

NUMBER	DEPTH	pH	SOURCE
	inches		
1	6	7.5	Slope
2	6	7.5	Slope
3	6	7.5	Slope
4	6	7.5	Slope
5	6	7.5	Slope

TABLE 7

Black limestone soil—Ulmus crassifolia, dominant, few Quercus Virginiana; rarely Sabina sabinoides

NUMBER	DEPTH	pH	SOURCE
	inches		
1	6	7.9	Along creek bank
2	6	7.9	Clear level ground
3	6	7.9	Clear level ground
4	6	7.9	Clear level ground
5	6	7 8	Clear level ground
6	6	7.6	On slope
7	6	7.8	Clear ground
8	6	7.8	Clear ground

large boulders of sandy, calcareous rock. The topography, however, is different; that in table 4 is marked by a decided slope terminating in a ravine, whereas that in table 5 is decidedly level, and therefore affected very little by leaching processes.

The areas treated in tables 6 and 7 both have their individual surface characteristics and topographic features. The soil in table 6 is usually composed of loose calcareous material, largely from the Austin chalk, and colored a dark gray by organic substances from decomposed plant remains, whereas that of table 7 is a fairly heavy black soil deposited by flood waters from nearby slopes.

The topography of the area in table 6 is characterized by slopes, cut by small ravines. In table 7 the ground is practically level, the area being an old flood plain

The results from these areas seem to be very definite. It has been pointed out before that ravines and low places where alluvium has been deposited, show a lesser H-ion concentration than the surrounding slopes and hills. Such a condition is represented by 5 and 6 in table 4. Practically all such places are characterized by elms and live oaks in this region.

If we can conceive of such a phenomenon as soil reaction interfering with dominance, then samples 1 to 4 and 7 in table 4 and 1 to 3, 5, and 6 in table 5 respectively, might be said to show such a condition. Neither *Quercus stellata*, *Q. Texana*, nor *Sabina sabinoides* seems to gain possession in table 4. In table 5, *Ulmus crassifolia* seem to be most frequent, but can not be said to be completely dominant. Sample 4 (table 5) was secured in an old, abandoned cotton field. Hence a higher concentration can be expected here, due to decomposed material from cultivated plants and probably leaching processes.

Comparing the area in table 6 with those in tables 4 and 5, *Sabina sabinoides* seems to have an affinity for a soil reaction value of 7.5, since it dominates neither in the area in table 4 nor 5 where the pH value is 6.9 and 7.6 respectively. A similar condition exists with respect to *Ulmus crassifolia* in the areas in tables 4, 5, and 7; in 4 and 5 where the reaction value is 6.9 and 7.6 respectively, *Ulmus crassifolia* has only an equal chance with *Quercus Virginiana*, *Q. Texana*, and *Sabina sabinoides*, whereas in 7 where the pH value 7.9, *Ulmus crassifolia* is found to be dominant.

CONCLUSIONS

1. The results from the two areas studied in the Bastrop region show that *Pinus taeda* occurs as a dominant in these areas in soil having a pH value of 6.7, whereas *Quercus stellata* and *Q. marylandica* dominate in the same areas where the soil reaction is pH 6.5.

2. In comparing the results from the Bastrop region with those obtained in other areas where *Quercus stellata* and *Q. marylandica* dominate, it seems as if these species have an affinity as dominants, for a pH value of about 6.5.

3. It has been pointed out that the difference in the pH value of the surface soil in the two areas at Bastrop is probably due to the fact that the surface soil in the pine timber rests on the Mt. Selman formation, whereas that in the oak-hickory association rests on the Carrizo formation.

4. The results from the areas in tables 4 and 5 indicate that *Quercus stellata*, *Q. marylandica*, *Sabina sabinoides*, and *Ulmus crassifolia*, occur as dominants at pH values of 6.5, 6.5, 7.5, and 7.8 to 7.9, respectively.

5. In general, the results obtained in this investigation seem to indicate that the soil reaction exerts a selective influence on plant species, but more data taken at different seasons of the year and over a period of years are necessary before definite conclusions can be drawn.

REFERENCES

(1) ARRHENIUS, O. 1922 The potential acidity of soils. *Soil Sci.* 14: 223–232.

(2) BRADFIELD, R. 1924 The effect of colloidal clay upon its hydrogen ion concentration. *Jour. Phys. Chem.* 28: 170–175.

(3) BRYAN, O. C. 1922 Effect of different reactions on the growth and nodule formation of soybeans. *Soil Sci.* 13: 271–303.

(4) CARLETON, E. A. 1923 A comparison of the Jones calcium acetate method for lime requirement with the hydrogen-ion concentration of some Quebec soils. *Soil Sci.* 16: 79–89.

(5) DEUSSEN, A. 1924 Geology of the coastal plain of Texas West of Brazos River. *U. S. Geol. Survey* Prof. Paper 126.

(6) DUVAL, H.: Manuscript yet unpublished.

(7) EMERSON, P. 1925 Soil Characteristics: A Field and Laboratory Guide. New York.

(8) GEISLER, S. 1926 Soil reactions in relation to plant succession in the Cincinnati region. *Ecology* 7: 163–183.

(9) GILLESPIE, L. J. 1920 Colorimetric determination of hydrogen-ion concentration without buffer mixtures with special reference to soils. *Soil Sci.* 10: 115–135.

(10) GILLESPIE, L. J., AND HURST, L. A. 1917 Hydrogen-ion concentration measurements of soils of two types: Caribau loam and Washburn loam. *Soil Sci.* 4: 313–319.

(11) GILLESPIE, L. J., AND HURST, L. A. 1918 Hydrogen-ion concentration—soil type—common potato scab. *Soil Sci.*, 6: 219–236.

(12) HESSELMAN, H. 1917 Om vara skogsforyngring-satgarders inverkan pa saltpeter-bildningen i marken ock dess betydelse for barrskogens foryngring. *Meddel. Sta.* skogsförsöksanst. No. 13–14 (pt. 2): 1221–1286.

(13) HISS, P. H. AND ZINSSER, H. 1910 A Textbook of Bacteriology. New York.

(14) JOFFE, J. S. 1920 The influence of soil reaction on the growth of alfalfa. *Soil Sci.* 10: 301–307.

(15) KELLY, A. P. 1923 Soil acidity an ecological factor. *Soil Sci.* 16: 41–57.

(16) KURZ, H. 1923 Hydrogen-ion concentration in relation to ecological factors. *Bot. Gaz.* 76: 1–29.

(17) LEWIS, I. M. 1915 The Trees of Texas. Univ. Texas Bul. 22.

(18) MIRASOL, J. J. 1920 Aluminum as a factor in soil acidity. *Soil Sci.* 10: 153–193.

(19) MOORE, B., AND TAYLOR, N. 1921 Soil acidity of a marine bog. *Ecology* 2: 258–261.

(20) NOYES, H. A., AND YODER, L. 1918 Carbonic acid gas in relation to soil acidity changes. *Soil Sci.*, 5: 151–161.

(21) PIERRE, W. H. 1925 The H-ion concentration of soils as affected by carbonic acid and the soil water ratio, and the nature of soil acidity as revealed by these studies. *Soil Sci.* 20: 285–305.

(22) PLUMMER, J. K. 1918 Studies in soil reaction as indicated by hydrogen electrode. *Jour. Agr. Res.* 12: 19–31.

(23) REED, G., AND KLUGH, A. B. 1924 Correlation between H-ion concentration and biota of granite and limestone pools. *Jour. Ecol.* 5: 272–275.

(24) SALISBURY, E. J. 1918 The oak-hornbeam woods of Hertfordshire. *Jour. Ecol.*, 4: 83–117.

(25) SALISBURY, E. J. 1922 Stratification and hydrogen-ion concentration of the soil in relation to leaching and plant succession, with special reference to woodlands. *Jour. Ecol.* 9: 220–240.

(26) SALISBURY, E. J. 1925 The incidence of species in relation to soil reactions. *Jour. Ecol.* 13: 149–160.

(27) SHARP, L. J., AND HOAGLAND, D. R. 1916 Acidity and adsorption soils as measured by hydrogen electrode. *Jour. Agr. Res.* 7: 123–145.

(28) Sharp, L. J., and Hoagland, D. R. 1919 Notes on recent work concerning arid soils. *Soil Sci.* 7: 197–200.

(29) Troug, E. 1916 The cause and nature of soil acidity with special regard to colloids and adsorption. *Jour. Phys. Chem.* 20: 457.

(30) Veitch, F. P. 1914 Comparison of methods for estimation of soil acidity. *Jour. Amer. Soc.* 26: 637–662.

(31) Waksman, S. 1922 Soil reaction and growth of Actinomycetes causing potato scab. *Soil Sci.* 14: 61–77.

(32) Wherry, E. L. 1920 Soil acidity and a field method for its measurement. *Ecology* 1: 160–173.

(33) Wherry, E. T. 1920 Plant distribution around salt marshes. *Ecology* 1: 42–48.

PHOSPHATE IN THE SOIL SOLUTION AS AFFECTED BY REACTION AND CATION CONCENTRATIONS[1]

L. J. H. TEAKLE[2]

University of California

Received for publication August 29, 1927

INTRODUCTION

The divergent results obtained from the use of phosphatic fertilizers under different soil and climatic conditions have led observers to rather opposed views on the behavior of phosphate in the soil system. A more intimate knowledge of soil chemistry and of the behavior of the various phosphates under the conditions met with in soils should satisfactorily answer the questions involved and harmonize the interpretations of field and laboratory results. This paper is intended to show the importance of the reaction of the medium in a study of the nature of phosphatic compounds and to indicate the importance of the several cations associated with phosphate in the soil under the range of acidity or alkalinity commonly occurring in soils.

SOIL PHOSPHATE

Forms

Phosphorus exists in the liquid and solid phases of all soils. Both organic and inorganic forms of phosphorus are known to be present.

Among the phosphatic compounds recognized by mineralogists may be mentioned apatite, wagnerite, wavellite, and vivianite. These minerals, as found by the geologist, are extremely resistant to the action of water, being but slowly decomposed. Other conditions probably prevail with regard to phosphates added in soluble form to the soil and to that phosphorus already in the organic cycle of the soil. Bassett (3), from a study of the application of the phase rule to calcium phosphates in the presence of calcium oxide, concluded that calcium hydroxy-apatite, $3Ca_3(PO_4)_2 \cdot Ca(OH)_2$, must be the form of phosphate existing in soils.

Certain organic compounds, containing phosphorus, have been isolated from

[1] Part of a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Plant Nutrition in the University of California.

[2] This problem was suggested by Professor J. S. Burd, division of plant nutrition, University of California, to whom grateful acknowledgment is made for advice and criticism throughout the investigation.

soils. Shorey (20) described the isolation of nucleic acid. Stoklasa (23) and Asō (1), working independently, claim the isolation of lecithin in small amounts. Schollenberger (18), Potter and Benton (13), and others, have claimed the separation of organic forms of phosphorus from the ammonia extract of soils. Although the inaccuracies of the methods of separation are apparent, *a priori* considerations of the system involved support the qualitative results.

Concentration of phosphate in the soil solution

In spite of the difficulties involved in obtaining the true soil solution, the work of many investigators, using water extraction, as well as displacement methods, shows that the soil solution is very dilute with respect to phosphate.

TABLE 1

The concentration of phosphate in the soil solution as determined by different investigators

INVESTIGATOR	METHOD USED	RANGE OF PO_4 CONCENTRATION, DRY SOIL	RANGE OF PO_4 CONCENTRATION IN SOLUTION
		p.p.m.	*p.p.m.*
Schultze (19)	1:5 extract	......	7 (good soil)
Ulbricht (24)	1:5 extract	......	Trace (poor soil)
Schloesing (17)	Water displacement	......	0.1–1.0
Schloesing (17)	1:5 extract	......	0.1–1.0
King (10)	1:10 extract	10–22	1.0–2.2 (calc.)
Whitney and Cameron (26)	1:5 extract	0.6–40 av. 6.0	0.1–8.0 (calc.)
Stewart (22)	1:5 extract	0.60–40	0.1–8.0 (calc.)
Ramann et al. (14)	Mechanical pressure	......	2–10
v. Wrangell (27)	Mechanical pressure	......	0.05–12 av. 0.2–0.9
Parker (12)	Water displacement	......	0.04–0.9 av. 0.1–0.3
Burd and Martin (4)	Water displacement	......	1.0–12.5
Morgan (11)	Oil displacement	1.1–4.6	3.3–15.7
Whitney and Cameron (26)	Centrifugal displacement	1.4–2.5	7–10

A summary of certain of the results obtained from the literature is presented in table 1.

It may be seen that the concentration of phosphate in the soil solution is seldom below 0.05 p.p.m. PO_4 and is seldom as high as 10 p.p.m. PO_4. The soil solution or extracting solution is saturated with respect to phosphate, as shown by the results of Burd and Martin (4), Schloesing fils (17), Stewart (22) and others, so that the results obtained by displacement or by water extraction may be comparable. Calculation of results on the dry soil basis gives an erroneous impression of the solubility of the soil phosphate.

Solubility

The low concentration of phosphate in the soil solution has been explained in two ways:

1. *The adsorption hypothesis.* Russell and Prescott (16) concluded that the fixation of phosphate by the soil involved the phenomenon of adsorption, and the results could be expressed by the well known Freundlich Equation $\frac{x}{m} = k\ C\frac{1}{p}$. Wrangell (28, p. 645) subscribes to this idea as she states, "Die Konzentration der Bodenlösung wird in weit grosserem Masse von der Absorption-kräften des Bodens abhangen als von der Natur seiner Phosphate." Apparently the fixation of phosphatic fertilizers is regarded as being strictly comparable with the absorption of gases by charcoal.

2. *The hydrolysis hypothesis.* The effect of water and of aqueous solutions on various phosphates has been carefully studied by some of the earlier chemists.

Cameron and Bell (5) proposed the following reactions:

$$1.\ \underline{CaH_4(PO_4)_2 \cdot H_2O + H_2O} = \underline{CaHPO_4 \cdot 2H_2O} + H_3PO_4$$

$$2.\ \underline{3CaHPO_4 \cdot 2H_2O} + H_2O = \frac{Ca_3(PO_4)_2}{\text{Amorphous}} + H_3PO_4$$

as it was found that the ratio of Ca:PO_4 is always lower in the liquid phase than in the solid phase.

Warington (25) found that treatment of dicalcium phosphate with successive portions of water resulted in the formation of a basic compound corresponding to

$$3Ca_3(PO_4)_2 \cdot Ca(OH)_2.$$

The more recent work of Comber (6) indicates the importance of the cations calcium, iron, and aluminum in controlling the phosphate concentration of the soil solution.

EXPERIMENTAL

The following experiments were designed to afford further evidence on the chemistry of phosphate. An attempt was made to study the effect of adjustment of the soil reaction by the use of strong acids on the phosphate concentration of the soil solution. The effect of precipitating the soluble calcium by means of ammonium oaxlate was expected to throw light on the solubility of the phosphatic compounds of the soils. The results were subjected to a critical examination in the light of results obtained from a study of the concentration of phosphate, at various reactions, in the presence of cations commonly present in soil, when pure solutions were used.

Methods

The soil solution was obtained by the displacement method described by Burd and Martin (4). The soils were displaced at a moisture content as near optimum as possible.

The analytical procedures in general use in plant nutrition laboratories were employed throughout. The results reported are averages of closely agreeing duplicate determinations.

Moisture was determined by drying at 100°C. for at least twelve hours. The results were calculated as percentage of water, on the moist soil basis.

For the determination of phosphate in small amounts, the coeruleo-molybdate method, described by Atkins (2), was found to be rapid, simple, and accurate if all precautions were taken to eliminate possible contamination.

TABLE 2

Description of soils used in this experiment

LABORATORY SERIAL NUMBER	SOIL SERIES (CALIFORNIA SURVEY)	ORIGIN	CROPS GROWN	PAST TREATMENT
29	Oakdale Sandy loam	Stanislaus County, J. Skittone Ranch, Salida, Calif.	Grapes	Uncropped. Edge of vineyard
30	Fresno Fine sandy loam	San Joaquin Valley, G. Christensen Ranch, Fresno, Calif.	Grapes	Originally grain. Now edge of vineyard 24 years old
33	Not mapped. Sandy loam.	Creek bottom Putah Creek, Univ. Farm, Davis, Calif.	None	None
35	Loam, probably Holland	Santa Cruz Mts., Bonny Doone Ranch, Santa Cruz, Calif.	Prunes (poor growth)	Unfertilized soil between rows

TABLE 3

Analysis of soils for total phosphorus

SOIL NUMBER	TOTAL PHOSPHORUS
	per cent PO_4
29	0.24
30	0.18
33	0.16

Soils

California soils were used throughout.

Soil 30 (table 2) has been studied intensively in this laboratory as soil 8 during the past eleven years. The other samples were obtained for the purposes of this problem or were available for experimental purposes.

Soil 33 is a gray, sandy loam soil and was obtained from a wash in the bed of Putah Creek, University Farm, Davis, California.

Analysis for total phosphorus was made, using the method described by Hopkins (9, p. 630). The samples were completely decomposed by fusion with sodium peroxide. The results, expressed in table 3, show that all of the soils were amply supplied with solid phase phosphorus.

Organic phosphate in the displaced solution

Appropriate aliquots were treated with magnesia mixture in the usual way. After standing for several days, the solutions were filtered and the precipitates washed with 2.5 per cent ammonia. The inorganic phosphate, presumably precipitated as ammonium magnesium phosphate, was dissolved on the filter with 1:9 HNO_3 and determined as the phospho-molybdate. After evaporation to dryness and ignition, the phosphate content of the first filtrate and the residue not dissolved by the nitric acid treatment, were determined by the same method. The results of determinations made on several solutions are reported in table 4.

TABLE 4

Soils 29, 30, and 33—separation of "inorganic" and "organic" phosphorus

SOIL NUMBER	TREATMENT	INORGANIC PO_4	ORGANIC PO_4
		p.p.m.	*p.p.m.*
29	Distilled water*	24.2	Trace
30	Distilled water*	55 0	Trace
30	0 03 *N* HCl*	40.0	Trace
30	0.1 *N* HCl*	75 0	Trace
30	Saturated ammonium oxalate	307.0	38 0
33	0.5 saturated ammonium oxalate	0 2	0.6
33	Saturated ammonium oxalate	0.6	4 4

* Solution obtained by continuing the displacement of the soil with distilled water after the recovery of the original soil solution. The solution was highly colored amber and contained considerable quantities of organic matter, some of which was flocculated by treatment with magnesia mixture.

These figures indicate that organic phosphorus is of little or no importance in the displaced solutions of soils 29 and 30 under natural conditions. Treatment with ammonium oxalate resulted in the liberation of appreciable quantities of organic phosphorus in soils 30 and 33.

Ammonium oxalate treatment

The relatively high concentration of phosphate in the displaced solution obtained from soil 30 suggested that additions of ammonium oxalate might materially affect the phosphatic compounds of this soil. Samples of the air-

dry soil were treated with varied amounts of ammonium oxalate (table 5). A little toluene was added to each treatment, to prevent bacterial decomposition of the oxalate (8). Sufficient distilled water was used with the oxalate to bring the soil to the optimum moisture condition.

After 3 days, allowed for the attainment of equilibrium, the soil solutions were displaced and analyzed. The results are expressed in table 5. The solutions obtained, following the higher treatments with ammonium oxalate,

TABLE 5

Soil 30—effect of ammonium oxalate, and of ammonium oxalate followed by calcium and iron as chlorides, on the displaced solution

NUMBER	TREATMENT	SPECIFIC RESISTANCE	pH	NH_4	Ca	PO_4	MOISTURE
		ohms		*p.p.m.*	*p.p.m.*	*p.p.m.*	*per cent*
1	Distilled water	800	7.8	.....	154	9.6	13 5
2	0.1 saturated $(NH_4)_2C_2O_4$	505	8.0	.....	138	11 1	13.7
3	0.2 saturated $(NH_4)_2C_2O_4$	495	7.8	260	48	36	13.7
4	0.3 saturated $(NH_4)_2C_2O_4$	415	7.9	428	Nil	96	13.5
5	0.4 saturated $(NH_4)_2C_2O_4$	238	7.8	824	Nil	163	13.6
6	0.5 saturated $(NH_4)_2C_2O_4$	156	7 7	1,530	Nil	194	13.7
7	0.6 saturated $(NH_4)_2C_2O_4$	95	7.8	2,280	Nil	206	13.6
8	0.7 saturated $(NH_4)_2C_2O_4$	80	...	2,620	Nil	206	13.8
	0.32 saturated $(NH_4)_2C_2O_4$ followed by						
9	Distilled water	284	...	728	Nil	103	12.9
10	550 p.p.m. Ca	190	...	872	Nil	56	12.8
11	1,100 p.p.m. Ca	128	7.8	1,128	92	26	12.6
12	1,650 p.p.m. Ca	98	7 6	1,368	212	12.5	12.6
13	2,200 p.p.m. Ca	81	7.5	1,504	384	11.3	12.6
14	11,000 p.p.m. Ca	25	7.5	2,216	7,840	8.0	12.6
15	1,320 p.p.m. Fe	110	6.0	1,224	Nil*	8.2	12.7

* Displaced solution gave no test for Ca or oxalate ion.

were inky black and contained appreciable quantities of phosphorus in organic combination (table 4).

Reprecipitation of the phosphate liberated by the action of ammonium oxalate, was brought about by additions of calcium chloride and ferric chloride. A large sample of soil was treated with 0.64 saturated ammonium oxalate to bring it to half optimum moisture content. After 2 days, subsamples were taken and brought to the optimum moisture conditions with distilled water containing varied amounts of the salts. Five days later, the soil solutions were displaced and analyzed. The effect of the salts was not only to precipitate the phosphate but also to clarify the solutions.

The results reported in table 5 show that the phosphate concentration is reduced to the original concentration by additions of calcium chloride or iron

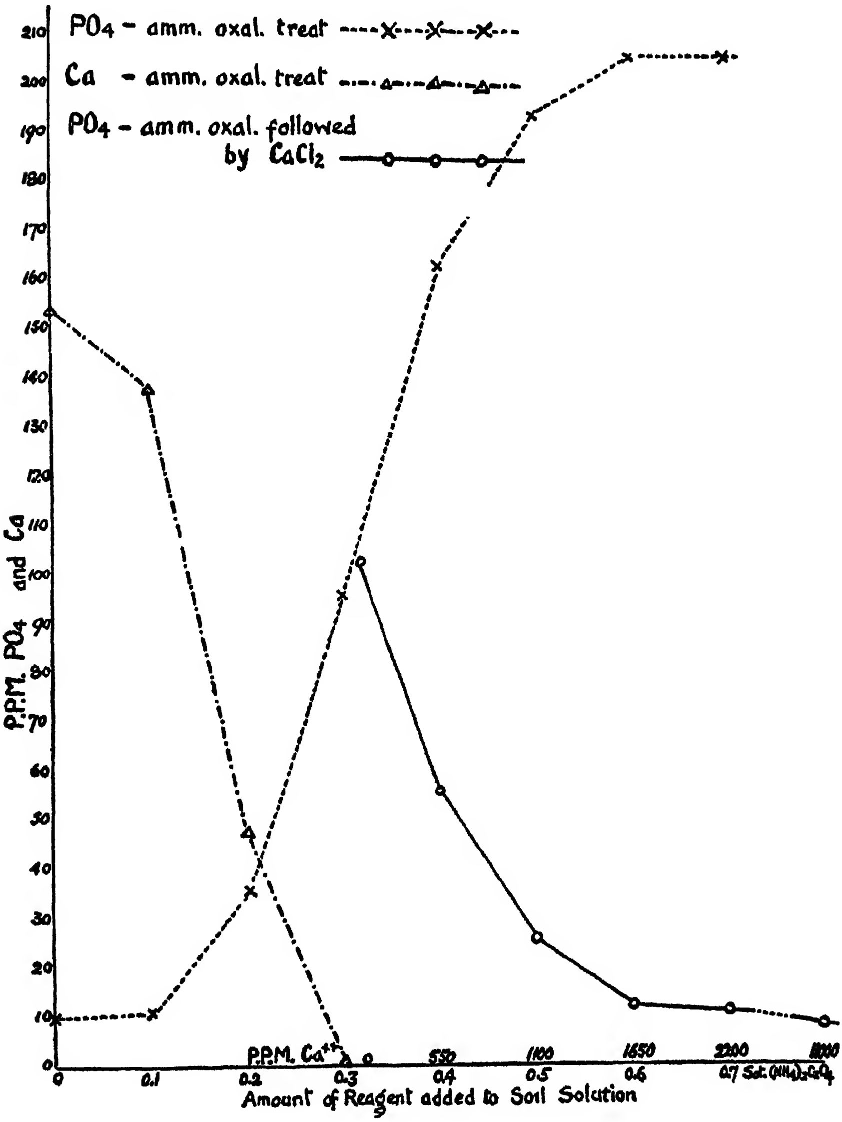


FIG. 1. EFFECT OF TREATMENT OF SOIL 30 WITH AMMONIUM OXALATE, AND WITH AMMONIUM OXALATE FOLLOWED BY $CaCl_2$, ON THE CONCENTRATION OF PO_4 AND CA IN THE DISPLACED SOLUTION

chloride. The reactions of the solutions are but slightly affected by this treatment. These results are expressed graphically in figure 1.

The action of the iron chloride is probably indirect and in accordance with the following reactions:

$$FeCl_3 + 3H_2O = Fe(OH)_3 + 3HCl \quad (A)$$
$$Ca(\text{Soil Complex}) + 2HCl = H_2(\text{Soil Complex}) + CaCl_2 \quad (B)$$
$$3\,CaCl_2 + 2PO_4''' = Ca_3(PO_4)_2 + 6Cl^- \quad (C)$$

The hydrochloric acid will affect the soil reaction as shown in table 5. In addition, it will liberate soil calcium not replaced by treatment with ammonium oxalate. This will precipitate the phosphate and excess oxalate in accordance with the results reported in table 5.

The effect of ammonium oxalate on soils 33 and 35 is reported in table 6. The displaced solutions from these soils are extremely low in phosphate. Hence it would be predicted that there would be no reaction between the oxalate and the phosphate, the solubility product of the calcium and phosphate being smaller than that of calcium and oxalate—assuming the phosphate to exist as a calcium salt in these soils. This prediction is supported by the results. The small increase in phosphate obtained is due largely to organic forms (table 4) in soil 33. It seems reasonable to expect analogous conditions in soil 35.

TABLE 6

Soils 33 and 35—effect of ammonium oxalate on the phosphate concentration of the displaced solution

SOIL NUMBER	TREATMENT	pH	TOTAL PO_4
			p.p.m.
33	Distilled water	7.0	0 36
33	0.5 saturated ammonium oxalate	7.5	0.8
33	Saturated ammonium oxalate	?	5.0
35	Distilled water	6 8	0.4
35	0.5 saturated ammonium oxalate	7.2	2.3

Treatment of soils with strong acids

Hydrochloric acid.—Previous experiments in this laboratory had indicated that treatment of a soil with dilute hydrochloric acid caused:

1. An increase in the concentration of phosphate in the displaced solution.
2. A falling off in the magnitude of this concentration with further small additions of acid (unpublished data).

These results suggested further experiments, which were conducted on soils 29 and 30.

Soil samples were moistened with one-half of the volume of distilled water calculated to bring the soil to optimum moisture conditions. Normal hydrochloric acid was then added with sufficient distilled water to bring the soil to

TABLE 7

Soil 29—analyses of displaced solution

August 21 to December 10, 1925

	TREATMENT 1—CONTROL			TREATMENT 2—0.08 N HCl			TREATMENT 3—0 2 N HCl		
Date moistened	8/21	...	...	8/26	.....	....	8/28	....	.....
Date displaced	8/28	10/27	12/9	9/2	10/15	12/10	9/5	10/15	12/10
Moisture...*per cent*	10 6	10 3	10.2	10.2	11.1	10.3	10.0	11.0	10.3
Sp. res...*ohms*	773	515	502	113	122	113	54	58	59
pH	6.8	6.8	7.1	6.3	6.5	6.7	5.6	6.1	6.4
PO_4...*p.p.m.*	7.5	8.0	9.4	7.3	10.9	9.3	2.5	7.3	7.7
NO_3...*p.p.m.*	462	769	716	330	508	680	332	335	362
HCO_3...*p.p.m.*	62	44	33	38	27	33	19.5	24	39
Cl...*p.p.m.*	44	96	120	2,890	.....	2,720	7,460	.....	6,300
SO_4...*p.p.m.*	111	110	149	74	73	168	54	52	68
SiO_2...*p.p.m.*	50	64	59	124	122	118	280	243	199
Ca...*p.p.m.*	160	216	232	1,220	1,080	1,250	3,050	2,640	2,650
Mg...*p.p.m.*	61	72	86	330	285	350	680	640	674
K...*p.p.m.*	56	52	65	189	131	132	311	157	155
Na...*p.p.m.*	20	22	23	66	35	64	127	56	46
Al...*p.p.m.*	1.0	...	...	.....	.....	.....	.....	.....	.....
Fe...*p.p.m.*	1.3	...	...	1.2	.....	.....	3.9	.....	.....
Mn...*p.p.m.*	0.5	0 8	0.2	49	.....	84	242	.....	281

TABLE 8

Soil 30—Analyses of displaced solution

September 7 to December 12, 1925

	TREATMENT 1—CONTROL			TREATMENT 2—0.03 N HCl			TREATMENT 3—0.1 N HCl		
Date moistened	9/7	.....	...*	9/9	...	.....	9/12	.....	.....
Date displaced	9/15	10/31	12/14	9/17	10/29	12/12	9/19	10/29	12/12
Moisture...*per cent*	14 0	14.6	14 3	13.8	14 6	14.0	13.9	14.3	13.5
Sp. res...*ohms*	580	233	540	224	225	202	98	106	108
pH	7.0	7.1	7 3	6.5	6.6	6.5	5.8	6.3	6.1
PO_4...*p.p.m.*	7.2	10.2	9.2	14.5	15.4	13.9	41.4	26.4	26.5
NO_3...*p.p.m.*	576	1,052	840	524	720	948	456	536	780
HCO_3...*p.p.m.*	135	83	51	64	49	42	42	54	36
Cl...*p.p.m.*	88	684	68	1,096	...	1,060	3,510	.....	2,780
SO_4...*p.p.m.*	97	.....	....	85	111	.....	73	97	.....
SiO_2...*p.p.m.*	53	.....	63	.....	...	118	.....	196	200
Ca...*p.p.m.*	207	380	232	580	600	670	1,540	1,430	1,330
Mg...*p.p.m.*	64	.....	71	156	173	192	335	324	343
K...*p.p.m.*	50	.....	...	76	67	.....	132	115	.....
Na...*p.p.m.*	33	.....	...	38	73	.....	42	64	.....
Fe...*p.p.m.*	1.4	.....	1.0	1.1	1.5	1.3	1.3	1.3	1.3
Mn...*p.p.m.*	0.16	.....	Trace	1.5	1.1	1.1	62	83	69

* New sample, as analysis indicated contamination of the original sample; probably due to NaCl absorbed by the crock in previous experiments.

the desired moisture content. It was thought that this procedure would ensure a better distribution of the action of the acid on the soil. After standing in loosely covered, earthenware crocks for 1 week, samples were taken for displacement of the soil solution. The remainder of the soil was sampled at later dates as reported in tables 7 and 8. The moisture conditions were maintained during this period by appropriate additions of distilled water.

Two treatments were given each soil, amounts of acid commensurate with the buffer system of the soil being used. Samples treated with distilled water were used as controls.

Analyses of the displaced solutions, obtained periodically during the experiment, are reported in tables 7 and 8.

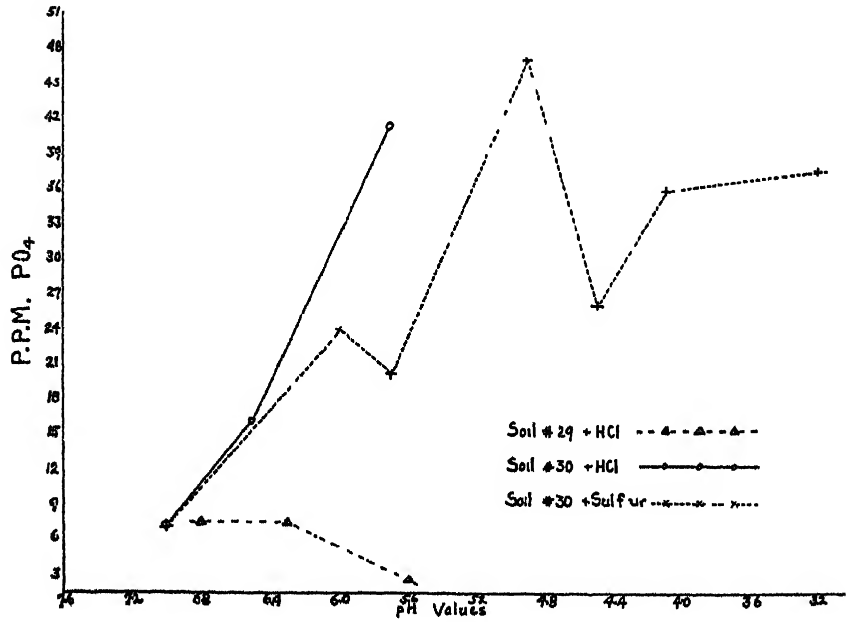


FIG. 2. EFFECT OF TREATMENT WITH HCl AND SULFUR ON THE REACTION AND PO_4 CONCENTRATION OF THE DISPLACED SOLUTION

The difference in the response of the two soils is in keeping with the results of the previous findings (fig. 2). The rôle of manganese in this behavior is illustrated by the results of an experiment in which 250 p.p.m. Mn was added to a solution prepared to approximate the composition of the displaced solution of soil 30. This is designated solution 1. The results expressed in table 9 indicate that manganese may have been responsible for the precipitation of phosphate in soil 29 under treatment with hydrochloric acid.

Sulfur treatment.—In order to test the direct effect of sulfur oxidation on the displaced solution, air-dry samples of soil 30 were mixed with different

amounts of flowers of sulfur and brought to optimum moisture condition with distilled water. Samples were taken for displacement at the various periods indicated in table 10.

The production of sulfuric acid caused an increase in the phosphate concentration of the displaced solution. This increase was limited by other factors, the result of interaction between the soil and the acid. Treatment with ammonium oxalate (table 5) showed the presence of ample quantities

TABLE 9

Analysis of solution 1, and of solution 1 fortified by addition of 50 p.p.m. PO_4, after the addition of 250 p.p.m. Mn as $MnSO_4$*

	Solution 1		Solution 1 fortified with 50 p.p.m. PO_4	
	a	b	a	b
pH adjusted	6.0	7.0	6.0	7.0
PO_4 ... *p.p.m.*	11.6	6.4	5.2	3.0

*Solution 1 contained 11.8 p.p.m. PO_4.

TABLE 10

Soil 30—Analysis of the displaced solution obtained at intervals during the progress of sulfur oxidation

September 12 to December 15, 1925

	Control		200 p.p.m. S		750 p.p.m. S		1500 p.p.m. S	
Date moistened	9/12	.....	.....	.....	.....	.....	.....	.....
Date displaced	9/15	12/14	11/6	12/15	11/6	12/15	11/6	12/15
Moisture ... *per cent*	14.0	14.3	14.0	14.0	14.0	14.3	14.0	14.2
Sp. Res. ... *ohms*	580	540	215	210	183	178	171	71
pH	7.0	7.3	6.0	5.7	4.9	4.3	4.1	3.2
PO_4 ... *p.p.m.*	7.2	9.2	24	20	47	26	36	38
SO_4 ... *p.p.m.*	97	.....	2,304	2,530	3,460	3,940	3,890	8,920
NO_3 ... *p.p.m.*	576	840	936	913	612	575	532	536
Cl ... *p.p.m.*	88	68	60	61	44	43	52	61
HCO_3 ... *p.p.m.*	135	51	34	24	20	5.0	Nil	Nil
SiO_2 ... *p.p.m.*	53	63	.....	216	.....	420	.....	498
Ca ... *p.p.m.*	207	232	907	920	950	640	770	600
Mg ... *p.p.m.*	64	71	240	260	408	680	595	1,310
Mn ... *p.p.m.*	0.16	Trace	Trace	4.0	91	105	148	250

of readily soluble phosphate, so evidently some cation released from the soil caused a precipitation of the phosphate. Owing to the solubility of phosphates of calcium and manganese at these reactions, it is probable that other cations are effective. Iron and aluminum may be suggested. The experiments of Stephenson and Powers (21) present a similar picture.

The results of acid treatment of the soils are shown graphically in figure 2.

The behavior of phosphate in various inorganic solutions

In order to determine the solubility of phosphate at various reactions and in the presence of certain cations commonly present in the soil, a series of experiments was conducted as follows:

Solubility of tricalcium phosphate.—Samples of Baker's C.P. tricalcium phosphate were distributed in 500-cc. bottles with convenient amounts of solutions of various compositions. After 6 days, during which frequent shakings by hand were given, the solutions were filtered and analyzed. The results are given in table 11.

TABLE 11

The solubility of Baker's C. P. tricalcium phosphate in various solutions

NUMBER	SOLUTION USED	Analysis of filtrate: pH	Ca: Parts per million	Ca: Milli-equivalents	PO_4: Parts per million	PO_4: Milli-equivalents
1	Distilled water	7	25.3	1 27	105	3 26
2	Distilled water containing 500 p.p.m. Ca^{++}	7	512	25.6	29.5	0 92
3	Distilled water containing 0.02 *N* NaOH	9	10 7	0 54	127	4 00
4	Distilled water containing 500 *p.p.m.* Ca^{++}	9	436	21.8	3 9	0.12
5	Distilled water (450) containing 5 *N* NaOH	?	No precipitate	.....	402	12.7

TABLE 12

Concentrations of stock solutions used in the following experiments

SALT USED	CONCENTRATION	NORMALITY
$CaCl_2$	60 0 mgm. Ca per cc.	3.0
$FeCl_3$	28.0 mgm. Fe per cc.	1.5
$AlCl_3$	25.3 mgm. Al per cc.	1.87
$MnCl_2$	48.8 mgm. Mn per cc.	1.78
NaH_2PO_4	144 4 mgm. PO_4 per cc.	4.55

A study of table 11 shows that the addition of hydroxyl ion leads to the liberation of phosphate, probably because of the formation of a basic phosphate. Hydroxyl ion is effective in reducing the concentration of phosphate in the presence of an excess of calcium. This is contrary to the ideas of Wityn (27), based on theoretical considerations. Apparently his assumptions were inadequate to meet the requirements of the system.

The precipitation of phosphate by different cations at various reactions.—It was desired to study a range of reaction in which each compound would be

relatively insoluble. The range varied considerably in position and magnitude with the various combinations used. This fact seems of paramount importance in a study of soil phosphate.

Stock solutions were prepared and carefully standardized. The concentrations are given in table 12.

TABLE 13

Solubility of phosphate in the presence of calcium at different reactions, using 10 cc. NaH_2PO_4 solution and the amounts of $CaCl_2$ solution and normal NaOH indicated, 950 cc. solution

NUMBER	$CaCl_2$	N NaOH	pH		Liquid Phase		SOLID PHASE		
			Original	Final	Ca	PO_4	Ca	PO_4	Ca: PO_4 equivalent
	cc.	cc.			p.p.m.	p.p.m.	p.p.m.	p.p.m.	
1	15	2.5	6.0	4.8	896	1,236	96	230	0.66
2	15	2.5	6.0	4.8	900	1,246	92	216	0.68
3	15	22.5	7.0	5.8	298	251	696	1,140	0.97
4	15	22.5	7.0	5.8	300	251	664	1,110	0.95
5	15	26.0	8.0	6.0	194	77	792	1,330	0.95
6	15	26.0	8.0	6.0	190	79	788	1,310	0.95
7	15	27.5	9.0	6.1	154	32.0	840	1,380	0.97
8	15	27.5	9.0	6.1	152	34.4	824	1,370	0.95
9	15	29.2	10	6.4	112	9.3	876	1,470	0.97
10	15	29.2	10	6.3	112	2.3	864	1,470	0.96
11	15	30.0	>10	6.3	......	3.0	.....	.....	.....
12	15	35.0	>10	>10	......	0.58	.....	.....	.....
13	15	40.0	>10	>10	......	0.17	.....	.....	.....
14	15	45.0	>10	>10	......	0.19	.....	.....	.....
15	15	50.0	>10	>10	......	0.38	.....	.....	.....
16	100	21.0	6.0	5.3	5,700	144	675	1,240	0.86
17	100	21.0	6.0	5.3	5,800	185	660	1,120	0.94
18	100	25.0	7.0	5.3	5,650	113	970	1,310	1.20
19	100	25.0	7.0	5.3	5,750	113	840	1,340	1.00
20	100	26.5	8.0	5.6	5,650	30	940	1,360	1.09
21	100	26.5	8.0	5.6	5,600	38	860	1,290	0.94
22	100	27.5	9.0	5.9	5,750	7	1,075	1,420	1.20
23	100	27.5	9.0	5.3	5,700	34	785	1,260	0.99
24	100	29 0	10	5.9	5,550	1.0	990	1,290	1.22
25	100	29.0	10	5.9	5,750	0.75	925	1,290	1.14
26	100	30 0	>10	6.0	......	2.0	.....	.....	.....
27	100	35.0	>10	8.6	......	10	.....	.....	.....
28	100	40.0	>10	>10	......	0.7	.....	.....	.....
29	100	45.0	>10	>10	......	Trace	.....	.....	.....
30	100	50.0	>10	>10	......	......	.....	.....	.....

The precipitates of the various phosphates were prepared by mixing 10 cc. NaH_2PO_4 solution with quantities of the solutions containing the desired cation so that an excess of cation was present. The mixing was done in about 800 cc. CO_2-free distilled water and the pH was adjusted with N NaOH. The volume was made up to 950 cc. and the solutions were transferred to liter bot-

tles. The bottles were corked and sealed with paraffine. After being shaken for 1 week in an end-over-end shaker, the solutions were filtered and analyzed. This period was found adequate by Cameron and Bell (5). A preliminary experiment showed equilibrium to be reached in this period. Determinations of pH were made immediately on opening the bottles following the period of

TABLE 14

Solubility of phosphate in the presence of iron at various reactions, using 10 cc. NaH_2PO_4 solution, 35 cc. $FeCl_3$ solution, and requisite amounts of normal NaOH in 950 cc. solution

NUMBER	*N* NaOH	pH		LIQUID PHASE		OBSERVATIONS	
		Original	Final	Fe	PO_4	Precipitate	Solution (filtrate)
	cc.			*p.p.m.*	*p.p.m.*		
1	Nil	1.5	1.9	900*	1,300*	None	Light, greenish, colloidal
2	15	2.0	2.1	570*	680*	Light brown floccules	Turbid
3	35	2.4	2.3	100*	330*	Brown floccules	Turbid
4	42	3.4	3.2	0.08	8	Brown floccules	Slightly turbid
5	44.5	4.0	3.8	0.05	13	Brown floccules	Almost clear
6	45	5.0	4.8	<0.05	27	Brown floccules	Clear
7	46	5–6	5.3	<0.05	34	Brown floccules	Clear
8	50	6–7	6.6	<0.05	60	Brown floccules	Clear
9	55	?	7.4	0.15	240	Brown floccules	Slightly turbid
10	70	?	9.6	1.0	1,000	Dark brown floccules	Slightly turbid

* Solution filtered turbid.

TABLE 15

Solubility of phosphate in the presence of aluminum at various reactions, using 10 cc. NaH_2PO_4 solution, 40 cc. $AlCl_3$ solution and requisite amounts of normal NaOH in 950 cc. solution

NUMBER	*N* NaOH	pH		LIQUID PHASE		OBSERVATIONS	
		Original	Final	Al	PO_4	Precipitate	Solution (filtrate)
	cc.			*p.p.m.*	*p.p.m.*		
1	34	3.4	3.4	600*	720*	None	Colloidal
2	75	4.6	4.2	150*	108*	Flocculent	Colloidal
3	87	6.2	6.2	6	3.8	Flocculent 6½ inches deep	Clear
4	90	7.6	6.8	Trace	0.56	Flocculent 6½ inches deep	Clear
5	117	>10	10.2	150*	500*	Flocculent	Colloidal

* Solution filtered turbid.

shaking. The electrometric method was used only when the magnitude of the reaction or the color of the solution prevented accurate colorimetric determinations.

The precipitates were drained on the filter and washed once with cold distilled water. They were then dissolved in 1:9 HNO_3 and made up to a volume of 1 liter when aliquots were taken for analysis.

The results are given in tables 13, 14, 15, and 16 and expressed graphically in figure 3.

DISCUSSION OF RESULTS

The concentration of phosphate in the soil solution

The results of investigations in practically all sections of the world have shown that the soil solution is very dilute with respect to phosphate. This is true regardless of the soil reaction, and applications of acids to the soils studied in this investigation have been shown to increase the concentration to but a limited extent. In fact, the results obtained from soil 29 show an absolute depression in the concentration of phosphate following the addition of hydrochloric acid. A consideration of tables 7 and 9 shows that manganese was responsible in this case. As the acidity of the soil is further increased, other cations, such as iron and aluminum, are brought into solution, and, in certain ranges of pH, may be effective in maintaining a low concentration of phosphate in the soil solution.

A great variety of phosphatic compounds is possible throughout the range of reaction met with in soils. Each cation considered is effective under certain conditions and there is sufficient overlapping of the ranges to form an efficient precipitating system in most soils (fig. 3). Some unsaturated soils are subject to leaching of phosphate applications. This is due to a lack of available bases at the reaction involved. In the case reported by Robinson and Jones (15), such a system is met with. Corrective measures should involve a change of the soil reaction and an increase in the soil cations other than hydrogen.

TABLE 16

Solubility of phosphate in the presence of manganese at various reactions, using 10 cc. NaH_2PO_4 solution, 40 cc. $MnCl_2$ solution, and requisite amounts of normal NaOH in 950 cc. solution

NUMBER	*N.* NaOH	pH		Liquid Phase		OBSERVATIONS	
		Original	Final	Mn	PO_4	Precipitate	Solution (filtrate)
	cc.			*p.p.m.*	*p.p.m.*		
1	4.2	5.4	4.6	1,920	1,200	Pink floccules	Clear
2	26.5	6.2	5.2	1,110	80	Pink floccules	Clear
3	32	7.4	6.3	890	1.6	Gray brown floccules	Clear
4	37	8.4	6.3	700	1.6	Gray brown floccules	Clear
5	79.5	>10	11.7	No test	280	Dark brown floccules	Clear

The phosphatic compounds of the soil

The crystalline phosphatic minerals of the soil were probably formed under conditions of heat and pressure, and are very slowly attacked by water. The phosphate cycle of the soil undoubtedly involves amorphous compounds resulting from the decay of organic matter. Soluble phosphatic fertilizers must augment this fraction. The crystalline forms must act as a reservoir.

The bases present in the soil solution, together with those liberated by base

replacement following the addition of a fertilizer are responsible for the precipitation of soluble phosphate. Of importance will be magnesium, calcium, manganese, iron, aluminum, and, perhaps, some others.

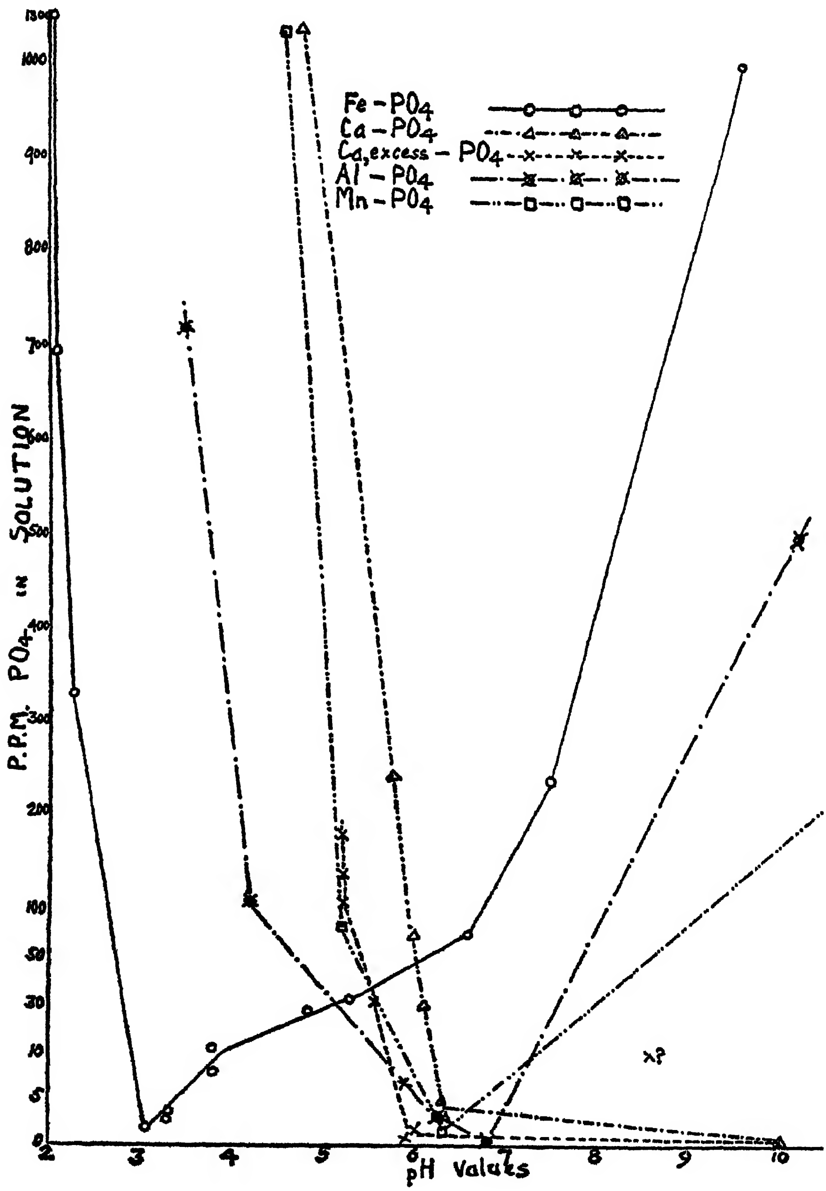


Fig. 3. Curves Showing Changes of Phosphate Solubility with Reaction in the Presence of Various Cations

Under neutral and slightly alkaline conditions, calcium and magnesium are the predominant soil bases and in normal soils are available for reaction with phosphate. No doubt calcium (or magnesium) phosphate is formed, withdrawing the soluble phosphate from solution in accordance with the well-known solubility laws (table 13; fig 3.).

Under slightly acid conditions, calcium phosphate is noticeably soluble, and manganese and aluminum are probably important in maintaining a low phosphate concentration in the soil solution (tables 7, 9, 15, and 16; fig. 3).

Iron in combination with phosphate is important under very acid conditions only (table 14; fig. 3). Under conditions of less acidity, the hydroxide is formed at the expense of iron phosphate, as the solubility product of Fe^{+++} and OH^- is of such a magnitude as to favor the reaction in this direction.

A basic calcium phosphate probably forms under alkaline conditions. Evidence for this is obtained from Bassett (3) who suggested $3Ca_3(PO_4)_2 \cdot Ca(OH)_2$. The effect of NaOH on tricalcium phosphate (table 11) indicates the formation of a basic calcium phosphate with the liberation of the excess phosphate.

The following reactions are proposed as indicating the behavior of phosphate in the soil:

1. Very acid conditions:

$$FePO_4 + 3\,OH^- \underset{\text{below pH 3}}{\overset{\text{above pH 3}}{\rightleftarrows}} Fe(OH)_3 + PO_4^{\equiv}$$

2. Slightly acid conditions:

$$\text{a. } Mn_3(PO_4)_2 + 6OH^- \underset{\text{below pH 6}}{\overset{\text{above pH 6}}{\rightleftarrows}} 3\,Mn(OH)_2 + 2PO_4^{\equiv}$$

$Mn(OH)_2$ is likely to oxidize, and in the presence of air forms the brown manganic oxide according to the reaction:

$$4Mn(OH)_2 + O_2 = 2Mn_2O_3 + 4H_2O.$$

$$\text{b. } AlPO_4 + 6OH^- \underset{\text{below pH 7}}{\overset{\text{above pH 7}}{\rightleftarrows}} AlO_3^{\equiv} + PO_4^{\equiv} + 3\,H_2O.$$

3. Neutral and alkaline conditions:

$$Ca_3(PO_4)_2 + 6\,OH^- \longleftarrow 3Ca(OH)_2 + 2PO_4^{\equiv} \qquad (A)$$

$$\left(x + \frac{y}{3}\right) Ca_3(PO_4)_2 + 2yOH^- \xrightarrow{\text{alkaline}} xCa_3(PO_4)_2 \cdot yCa(OH)_2 + \frac{2y}{3} PO_4^{\equiv} \qquad (B)$$

It is recognized that this method of presentation is likely to be misinterpreted, but it is deemed of value in suggesting possible reactions. The pH values given in the equations are indicative of the position in the pH scale at which the reactions may occur. It must be emphasized that it is inconceivable that absolutely definite pH values are concerned, but that ranges, more or

less circumscribed, are involved. Much further and more detailed work will be necessary in order to complete the evidence for these reactions.

Adsorption of phosphate

Although Fisher (7) and Comber (6) have shown the fallacies of the early paper of Russell and Prescott (16), and Comber has indicated the importance of cations in the behavior of phosphate and oxalate in soils, more detailed work appears to be necessary to convince the proponents of the adsorption theory. This paper attempts to show the effect of the various cations at different reactions on the phosphate concentration of solutions. The results indicate that the normal chemical process of precipitation is adequate to explain the behavior of phosphate in soils when the phenomenon of base exchange is recognized. That adsorption may play some part cannot be denied with the evidence at hand. Some suggestions from the data of table 5, which shows the effect of treatment of soil 30 with ammonium oxalate, support the chemical theory. If a balance sheet of the reactions, in terms of equivalents, be drawn up from the results expressed in this table, it will be found that within about 10 per cent, the anions and cations balance. This is considered to be within the limits of error under the conditions of the experiment. At most, adsorption may play a minor rôle under these conditions. A more thorough chemical picture of soils and of soil processes, using quantitative methods, seems the most promising avenue for the attainment of a solution of many soil problems.

SUMMARY AND CONCLUSIONS

Experiments were conducted to study:

1. The solubility of phosphates in aqueous solutions at various reactions.
2. The solubility of phosphates in soils under treatment with various reagents. Water, hydrochloric acid, sulfur, and ammonium oxalate were used.

The following conclusions are drawn from a consideration of the results:

1. Iron phosphate is least soluble under acid conditions corresponding to pH 3. Under less acid conditions, ferric hydroxide is precipitated at the expense of ferric phosphate with the liberation of phosphate ions.
2. Manganese and aluminum phosphates are least soluble under slightly acid conditions. Manganic oxide is precipitated, with the liveration of phosphate, as the conditions become alkaline. Aluminum phosphate forms aluminate ions and phosphate ions under alkaline conditions.
3. Calcium phosphate is insoluble under alkaline conditions.
4. The main factors in the depression of the solubility of calcium phosphate are: first, calcium ion, and second, excess calcium ion in the presence of hydroxyl ion. Hydroxyl ion alone probably causes the formation of a basic phosphate with the liberation of some phosphate ions.
5. Removal of calcium from the soil solution of soil 30 by means of ammonium oxalate caused a twenty-fold to fifty-fold increase in phosphate concentration. This phosphate may be precipitated by the addition of calcium or iron to this soil, reducing the phosphate concentration to the original figure.

6. This action does not occur in soils containing phosphate of low solubility only. It depends on the relation of the solubility products of calcium phosphate and calcium oxalate.

7. Comparison of the solubility of various phosphates in pure solutions with the concentrations found in the soil solution suggests that the chemical properties of the compounds account for the behavior of soil phosphates. Adsorption of phosphate is unimportant, if it occurs at all in soils.

8. Calcium is the base most important in controlling the phosphate concentration in neutral soils of the type studied.

9. Organic forms of phosphorous may constitute an important part of the total phosphorous of the displaced solution from certain soils, but *not* from others.

REFERENCES

(1) Asō, K. 1905 Ueber das Vorkommen von Phosphorsäure in organischen Verbindungen im Boden. *Biedermann's Zentbl.* 34: 3–4.

(2) Atkins, W. R. G. 1924 The rapid determination of available phosphate in soil by the coeruleo-molybdate reaction of Denigès. *Jour. Agr. Sci.* 14: 192–197.

(3) Bassett, H. 1917 The phosphates of calcium. Part IV. The basic phosphates. *Jour. Chem. Soc.* [London] 111: 620–642.

(4) Burd, J. S., and Martin, J. C. 1923 Water displacement of soils and the soil solution. *Jour. Agr. Sci.* 13: 265–295.

(5) Cameron, F. K., and Bell, J. M. 1907 The action of water and aqueous solutions upon soil phosphates. U. S. Dept. Agr. Bur. Soils Bul. 41.

(6) Comber, N. M. 1924 The rôle of the electronegative ions in the reactions between soils and electrolytes. *Faraday Soc. Gen. Discuss. "Base Exchange in Soils,"* p. 567–572.

(7) Fisher, E. A. 1922 The phenomena of absorption in soils: A critical discussion of the hypotheses put forward. *Trans. Faraday Soc.* 17: 305–316.

(8) Gimingham, C. T. 1911 The formation of calcium carbonate in the soil by bacteria. *Jour. Agr. Sci.* 4: 145–149.

(9) Hopkins, C. G. 1910 Soil Fertility and Permanent Agriculture. New York.

(10) King, F. H. 1904 Promising methods for the investigation of problems of soil and plant physiology, and some lines of investigation to which they are adapted. *Proc. Soc. Prom. Agr. Sci.* 1904: 171–190.

(11) Morgan, J. F. 1916 The soil solution obtained by the oil pressure method. Mich. Agr. Exp. Sta. Tech. Bul. 28.

(12) Parker, F. W., and Tidmore, J. W. 1926 The influence of lime and phosphatic fertilizers on the phosphorus content of the soil solution and of soil extracts. *Soil Sci.* 21: 425–441.

(13) Potter, R. S., and Benton, T. H. 1916 The organic phosphorus of soil. *Soil Sci.* 2: 291–298.

(14) Ramann, E., März, S., and Bauer, H. 1916 Über Bodenpresssäfte. Internatl. Mitt. Bodenk. 6: 1–26.

(15) Robinson, G. W., and Jones, J. O. 1927 Losses of added phosphate by leaching from N. Welsh soils. *Jour. Agr. Sci.* 17: 94–103.

(16) Russell, E. J., and Prescott, J. A. 1916 The reaction between dilute acids and phosphorus compounds of the soil. *Jour. Agr. Sci.* 8: 65–110.

(17) Schloesing Fils, Th. 1899 Etude sur l'acide phosphorique dissous par les eaux du sol. *Ann. Sci. Agron.* 1: 316–359.

(18) Schollenberger, C. J. 1918 Organic phosphorus of soil; experimental work on methods for extraction and determination. *Soil Sci.* 6: 365–395.

(19) Schultze, 1864 *Landw. Vers. Sta.* 6: 411. (Not read. Reference from Hilgard, E. W., *Soils*, p. 328.)

(20) SHOREY, E. C. 1913 Some organic soil constituents. U. S. Dept. Agr. Bur. Soils Bul. 88.

(21) STEPHENSON, R. E., AND POWERS, W. L. 1924 Influence of sulphur oxidation on solubility of soil minerals. *Soil Sci.* 18: 317–321.

(22) STEWART, G. R. 1918 Effect of season and crop growth in modifying the soil extract. *Jour. Agr. Res.* 12: 311–368.

(23) STOKLASA, J. 1911 Biochemischer Kreislauf des Phosphat-Ions im Boden. *Centbl. Bakt.* (II) 29: 385–519.

(24) ULBRICHT, 1863 *Landw. Vers. Sta.* 5: 207. (Not read. Reference from Hilgard, E. W., *Soils*, p. 328.)

(25) WARINGTON, R. 1873 On the decomposition of tricalcic phosphate by water. *Jour. Chem. Soc. (London)* 26: 983–989.

(26) WHITNEY, M., AND CAMERON, F. K. 1903 The chemistry of the soil as related to crop production. U. S. Dept. Agr. Bur. Soils Bul. 22.

(27) WITYN, J. 1925 Ueber die bessere Ausnutzung der im Boden befindlichen Phosphorsäure. *Ztschr. Pflanzenernähr. u. Düngung.* 6: 27–51.

(28) WRANGELL, M. V. 1926 Über Bodenphosphate und phosphorsäurebedürftigkeit. *Landw. Jahrb.* 64: 627–668.

THE EFFECT OF DEHYDRATION OF SOILS UPON THEIR COLLOID CONSTITUENTS: I[1]

J. L. STEENKAMP[2]

School of Rural Economy, University of Oxford

Received for publication September 9, 1927

INTRODUCTION

The beneficial effects on fertility of drying and burning soil have long been known. Many years before the beginning of soil science the Roman farmer was well acquainted with the increased fertility due to this treatment. The increased productivity caused by drying alluvial soils in direct sunlight has been fully recognized in India, where some of the natives make a practice of exposing their soils to this ameliorating influence. Among the Chinese there is an old practice of tearing out thoroughly dried "Kangs" that have been made of clay-substance, and using it as fertilizer. Even the old custom of using old garden walls made of loam, as a fertilizer, because of their efficacious effect on soil productivity is very well known.

In many parts of France and England the practice of burning, and of paring and burning soils, was very common at one time. This practice undoubtedly originated as a result of the extreme prevalence of marshy soils in Ireland, where burning of the surface of the ground on moorland to bring it into cultivation, was resorted to. It possibly spread from Ireland to England and Holland, and subsequently reached France and Germany.

It was thought at first by many soil investigators that the beneficial effects of drying and burning soil were due to a physical bettering of it; later, as chemistry developed, the increased growth was considered to be due to some chemical change which occurs in the soil during the process of drying; and a more recent view is that the improvement is brought about by re-adjustment in the microscopical life of the soil.

It is the purpose of this paper to present on physico-chemical lines some experimental data on the effect of dehydration on the colloidal constituents of soil, in order to throw more light on the problem of the increased fertility after drying.

REVIEW OF LITERATURE

Water-soluble constituents

The extensive literature bearing on the special physical, chemical, and biological effects of moisture changes in soils has been comprehensibly reviewed by Gustafson (6).

He reports from literature much careful experimental work on heating and drying soils, both before soil organisms were recognized, and in connection with soil biology. These studies show that drying and heating soil at 100°C. or higher, increase its productiveness, even though germination may be retarded and early growth depressed. They also show that the quantity of soluble mineral and organic constituents recovered by extraction with dis-

---

[1] Parts II and III will appear in the two subsequent numbers of *Soil Science*, respectively.

[2] This research was carried out under the supervision of Mr. C. G. T. Morrison, M.A., University Reader in Agricultural Chemistry, University of Oxford. To him the writer's grateful thanks are due for valuable suggestions and criticisms.

tilled water is increased by heating. The increase bears some relation to the temperature of heating, the maximum soluble constituents being found at about 250°C., above which the total salts recovered decrease.

Investigators are not in general agreement as to the effect on nitrates of heating at 100°C. Many workers note a decrease as the temperature is further raised and the almost total disappearance of nitrates at 250°C. Gustafson's own work shows a reduction of nitrates, if the temperature is raised above 100°C.

It appears from the literature that soil workers do not agree as to the cause of the increase in soluble matter due to drying and heating. Some hold the effect of heating to be largely physical; others say that it is mainly chemical, and still others lay most stress on the biological phase. Nearly all admit that the physical is usually a factor and others add colloids as a physico-chemical factor.

Gustafson's work shows that air-drying swamp soils, and oven-drying other soils (in oven at 105°C. for 8 hours), increased to a marked extent the quantity of water-soluble material removed by 1:5 extraction with distilled water. Also storing soils for 9 weeks at 8 to 12°C. in open jars, in which water evaporated was restored each week or in sealed tubes in its original condition, did not markedly affect the total soluble matter. Nitrification occurred in the open jars while nitrates decreased as a rule in the sealed tubes.

Buckman (2) concluded from the work of others that, under conditions of extreme dryness, an increase in moisture means an increase in nitrates. Lyon and Bizzel (15) found that an increase in moisture, after a dry period, was sometimes accompanied by an increase in nitrates in an unplanted soil; they also found with other investigators that steam sterilization increased the soluble matter of both organic and inorganic constituents, and this increase was particularly marked in the case of organic matter. According to Alway and Vail (1) the moistening and drying out of soils, under some conditions, causes a natural fertilization of the deeper layers, because the organic matter falls into the cracks.

Ehrenberg (4) states that many investigators have observed a bettering of the quality of a soil as a result of its drying out, and quotes Vaula as saying that the energetic drying out of soils rich in humus favors the quality of such soils especially.

The effects of drying the soil are sometimes injurious. Hilgard (8) reports injuries to plants caused by the drying and cracking of soils and the consequent mechanical tearing of the root systems. Sometimes the shrinking of the surface crust of soil around the stems of grain causes a constriction that is injurious. Ehrenberg has reported that a disease of sugar beet is traceable to such mechanical injury.

Kelley and McGeorge (13) studied the water and acid extracts of different soils that had been air-dried, and others that had been dried at higher temperatures. They found that, for most soils, the solubility of the constituents increased with the temperature of drying. Iron was an exception. The high solubility of the soils used in aquatic agriculture is, according to these investigators, decreased by drying. They say the subject is very complex, and among the many factors involved are flocculation of colloids, oxidation, deoxidation, decomposition, dehydration, and the attendant physical alterations of the soil film. A very recent and important work on this subject is that of Lebedjantzev (14).

He contends, on experimental data, that the change in fertility by drying is conditioned by the removal of water by evaporation, and by the heating of the soil by the rays of the sun; and draws the final conclusion that the process of drying is a powerful factor determining to a large extent the fertility of the soil under natural conditions. It probably plays an important, and hitherto unknown, rôle in all the processes of increasing the soil fertility by means of mechanical cultivation of soil.

With regard to the effect of the individual factors in the drying of soil, he found that the removal of water, and the increase in temperature, give a positive effect, whereas the effect of oxidation with oxygen, with the aid and influence of light is negative. In one case the removal of water acts more strongly than the increase in temperature, whereas in another the action of temperature is stronger than the increase in dehydration.

The effect on crop yield was determined by sowing on air-dried and wet soils, both then being kept at an optimum moisture content. In a large number of these pot experiments the drying of the soil was accompanied by an increase in the yield of oats, buckwheat, and millet. It is also worth noting that the greatest response was obtained with plants which under natural conditions thrive in soils not subjected to the drying influence in tilling operations (meadows); the least response, on the contrary, was obtained with cultivated plants exposed to the greatest artificial drying caused by cultivation in the row. Repeated drying also further increased the yield of the soil, and a maximum effect is apparently obtained with triple drying.

From the cited figures it is evident that the effect of drying is to a great extent dependent on the cultural conditions of the soil. Soils which are uncultivated or which carry a perennial crop, and are therefore undisturbed, are the most sensitive to drying; the effect produced on soils which are highly farmed is also considerable. Under ordinary conditions or arable farming, where a high state of fertility is not aimed at, the benefit is much smaller. Organic matter and nitrogen (ammonia and amide) are very soluble in uncultivated soils.

An experiment was also conducted to establish the locality of maximum fertility. It was found that the fertility of each of the overlying layers (layers of 20 cm.) increases as compared with the lower layer.

Finally, Lebedjantzer found that drying caused only a small change in the solubility of mineral substances; a large increase of organic substances, nitrogen, and phosphorus; an extremely large increase of ammonia nitrogen; and a slightly smaller increase of amide nitrogen while the number of microorganisms decreased very sharply. The variation in yielding capacity of the pots corresponds to the chemical changes, i.e. analysis, in the soil.

Shrinkage of soils

The marked decrease in volume of a soil on drying is well known. The magnitude of this decrease varies for different soil types, being greatest in clay soils, and least in sandy. The effect is seen in practice in the cracking of the ground surface, which occurs during prolonged spells of dry weather, especially in closely grained and heavy soil types.

This effect was not determined quantitatively until 1908 when Watts, and later Tempany (18), came to the same conclusions. The normal relation between contraction and loss of water for moistened (kneaded) soils appears to be that the cubical contraction is equal to the volume of water evaporated.

Soils which have been so kneaded to a point of maximum plasticity, probably hold the water in union with the colloidal matter present in the form of a gel, which occupies the whole of the interstitial spaces of the soil, and, as the soil loses water by evaporation, draws together the soil particles into its meshes. In normal soils, contracting in this way, a point is reached at which internal friction among the particles offers such resistance to the contracting pull of the gel as to cause a progressively increasing departure from normal relationship. This point, and the magnitude of total shrinkage observed, appears to be a function of the amount of colloidal clay contained in any particular example.

Hardy (7) criticises Tempany's hypothesis on the grounds that it does not completely hit the facts. In particular it fails to account for the abnormally low shrinkage coefficients exhibited by laterite soils. The hypothesis finally accepted is based on the belief that colloidal gels possess a reticulate structure. At the point of saturation a hydrogel probably contains water in two phases. The first of these is adsorbed in the walls of the gel whereas the second phase fills the vesicles of the gel and is a crystallline phase. He demonstrates that shrinkage in clays and soils is due solely to loss of vesicular water.

Fischer (5) found that imbibitional or gel water, held by the colloid, and capillary or interstitial water, held as wedges between the soil grains, evaporate simultaneously. The former water evaporates at a practically constant rate, whereas the latter evaporates at a rapidly diminishing rate.

Summary

1. Drying of a soil generally increases the solubility of inorganic as well as organic substances, and according to experience and experiment, previous drying of a soil is consequently usually favorable to its fertility. The increase bears some relation to the temperature of heating, the maximum of soluble constituents being found at about 250°C., above which the total salts recovered decrease.

2. The greatest response from drying a soil has been obtained for plants, which, under natural conditions, thrive in soils not subjected to the drying influence in tilling operations.

3. Experiments were conducted to show that the fertility of each of the overlying layers of 20 cm. increased as compared with the lower layer.

4. Data have been obtained, which show that this effect on fertility may be traced to physical, chemical, and biological causes, or a combination of them.

5. Experiments permit the conclusion that the change in fertility by drying is conditioned by the removal of water by evaporation, and by the heating of the soil by the rays of the sun, and that it is therefore one of the powerful factors which help to transform the fertility elements of the soil from a potential to an active form.

EXPERIMENTAL WORK

Although the reviewed literature on this subject seems fairly comprehensive in many ways, the specific effect on the soil colloids, from a physico-chemical point of view, when a soil is dried out, seems hardly to have had any attention, despite the fact that the colloidal constituents of a soil are important to plant existence. It is particularly from the physico-chemical viewpoint that the present work has been carried out.

Description of soils experimented on

Disturbed:

- Soil I. Sandy humus containing about 1 per cent clay and traces of calcium carbonate.
- Soil II. Light black clay-soil deficient in calcium carbonate.
- Soil III. Fairly heavy clay-soil containing calcium carbonate.

Undisturbed:

- Soil IIIb. Fairly heavy clay-soil. The sampling was made in the uncultivated section of the field of soil III.
- Soil IV. Fairly heavy yellow clay-soil deficient in calcium carbonate and contains very small percentage of humus.
- Soil V. Subsoil of IV.

Method of sampling and drying out of soils

Specimens, surface and subsoil, were obtained representing the soil types most commonly cultivated. These collected types range from sandy humus, light black clay, and fairly heavy clay to yellow clay pasture soil, some containing calcium carbonate. The surface soil was taken to a depth of 6 inches and the subsoil at a depth of 6 to 12 inches.

These samples were conveyed to, and stored, if necessary, in paraffin tins, the lids of which were closely sealed with paraffin wax, in order to reduce the loss of moisture to a minimum.

The wet soil was most effectually sieved by first cutting up soil into the thinnest possible slices, which with very slight mechanical treatment, easily went through a sieve of 3 mm. mesh. This was especially the case with the clay soils. Enough of the moist soil was sieved through for experimental purposes at different stages of dehydration.

The moist soil was dried, except for special experiments mentioned hereafter, by spreading it out in the laboratory on iron plates, and collecting it again after varying intervals of time, in order to obtain from well-mixed moist soil, samples which would contain decreasing amounts of moisture until an air-dried condition was reached. The final moisture was removed by leaving the moist soil in a steam oven for 24 hours.

At each stage of dehydration, the soil samples were weighed in rapid succession in order to obtain an accurate estimation of the water contents. The weighed-out soils at any particular water content were then immediately experimented upon.

The experimental work is divided into two sections; namely, dehydration effect, and reversibility of changes caused by dehydration.

DEHYDRATION EFFECT

Mechannical analysis

To discover the physical effect of dehydration on soil particles, it was proposed to make mechanical analyses of soils by two methods, one including and one excluding chemical reagents. The methods employed were those suggested by Robinson (16), including the method proposed to eliminate the effect of humus on the clay fraction, namely, destruction of humus by means of hydrogen peroxide oxidation.

Experimental. A very general and conspicuous result of these experiments is the decrease of the clay fraction, which is counter-balanced by increase of other fractions in all the treatments, according to the dryness of the soil. This cementing effect causes a very striking increase in the fine sand fractions for treatment *C*, in which case only distilled water had been used, and *D*, in which only H_2O_2 had been added, which would consequently cause a smaller increase of the fine sand fraction with treatment *D* than *C*. This deflocculating effect is clearly seen in the increase of the clay fraction in experiment *D*. On the other hand, experiments A, consisting of only fifth-normal hydrochloric acid and no ammonium hydroxide treatment, and *B*, fifth-normal hydrochloric acid and subsequently ammonium hydroxide treatment, show a definite increase in the silt fractions, according to dryness of the soil. Experiment *B*, because of the ammonium hydroxide, shows also an increase in the fine silt fraction.

The acid treatment, with or without ammonium hydroxide, gives a definitely higher percentage of clay than the other experiments. The decrease in percentage of clay in the latter treatment, however, is slightly sharper, so that in method *B*, with the solutions ordinarily used, the deflocculating effect of

ammonium hydroxide on cemented particles, according to dryness, is noticeable. Furthermore, when only distilled water is used, the decrease in clay percentage is quite considerable. Also the effect of hydrogen peroxide treatment seems to have had a slight deflocculating action on cemented material for both clay and sandy humus soils, since the decrease in clay fraction is less pronounced.

These results show that for accurate mechanical analysis the experiments ought to be performed with soils equally wet or dry. If the air-dried condition is taken for all soils, then the error would naturally depend on the type of soil taken, since the water contents in the air-dried condition would differ. Possibly for ordinary analysis this error would be negligible.

Degree of saturation

The part played by the degree of saturation of a soil is so important a factor in plant nutrition, that it was thought essential to investigate fully what effect drying out of a soil would have on the bases in question. To obtain the degree of saturation of a soil, two related factors must be taken into consideration:

1. The sum of the absorbed bases (S, expressed in equivalents) actually present in the soil.
2. The total quantity (T, in equivalents) which the soil is capable of binding,

$$\text{so that } V \text{ (degree of saturation)} = \frac{S}{T} \times 100.$$

Exchangeable and acid-soluble bases

Exchangeable bases. The method used in this experiment is the leaching-out one proposed by Hissink (10) for a clay soil, including also the slight modification for a sandy humus-soil, so that the separation of these bases from the acid-soluble bases and the calcium carbonate, is possible for soils containing no water-soluble salts.

Experimental. The effect of dehydration on the sum-total and individual exchangeable bases, at different stages of dryness of the soil, was determined for four different types of soils, the results of which are embodied in tables 2, 3, 4, 5, 7, and 11. The results of the uncultivated section of the field of soil III (table 4) are in table 7, and of the subsoil (V) of soil IV (table 5) are in table 11. The bases were estimated on 100 gm. dry soil in milligram-equivalents.

Sum-total exchangeable bases. The sums of the bases for different types of soil differ considerably according to decrease of water-content (see figs. 1 and 2). For sandy humus (I, fig. 1) fairly heavy clay soil (III, fig. 1), and light black clay soil (II, fig. 2) there is a distinct increase in exchangeable bases the more the soil is dehydrated, the increase being more prominent in the case of the light black clay-soil. On the other hand, for fairly heavy yellow clay-soil (IV,

fig. 2), subsoil of this yellow clay-soil (V, fig. 2), and fairly heavy clay (III b—which is similar to soil III, except that this sample was collected in the uncultivated section just outside the same field—fig. 1), there is again a definite

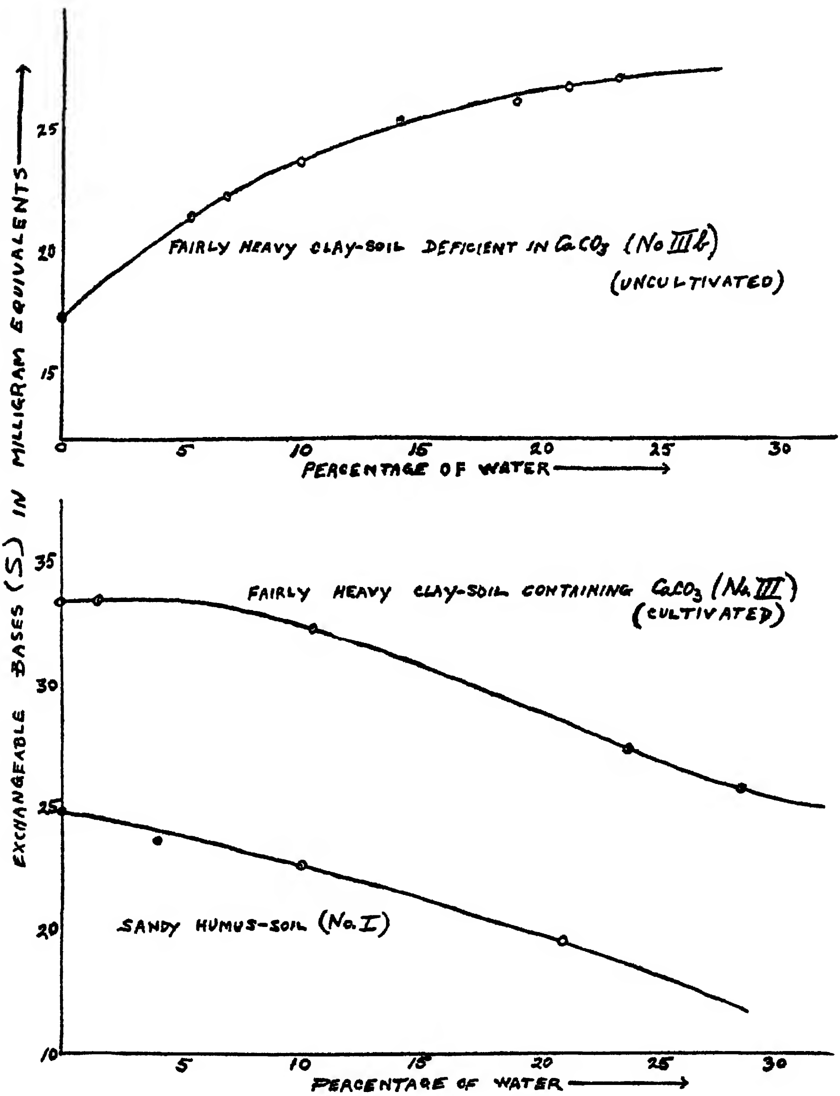


FIG. 1. EFFECT OF DEHYDRATION ON EXCHANGEABLE BASES

decrease of exchangeable bases as the soil becomes drier. The decrease is more or less the same for the clay soil (III b) and the yellow clay-soil (IV) whereas for the subsoil of IV it is less pronounced.

A striking difference between these two sets of soils lies in the fact that the set showing a decrease in bases, according to dryness, are all pasture soils. This difference is especially distinct in the case of soil III. The soil collected in the field itself, which is under cultivation, gives a definite increase of bases, when dried out, whereas the sample taken just outside, under grass and apparently never under cultivation, because of its position in the corner of the field, shows a very pronounced decrease of exchangeable bases. This phenomemon is, therefore, possibly due to the degree of weathering. However, this point, and also the curious curvatures near the closing stages of dehydration for soils III, II, and V (see figs. 1 and 2), require special attention and are fully dis-

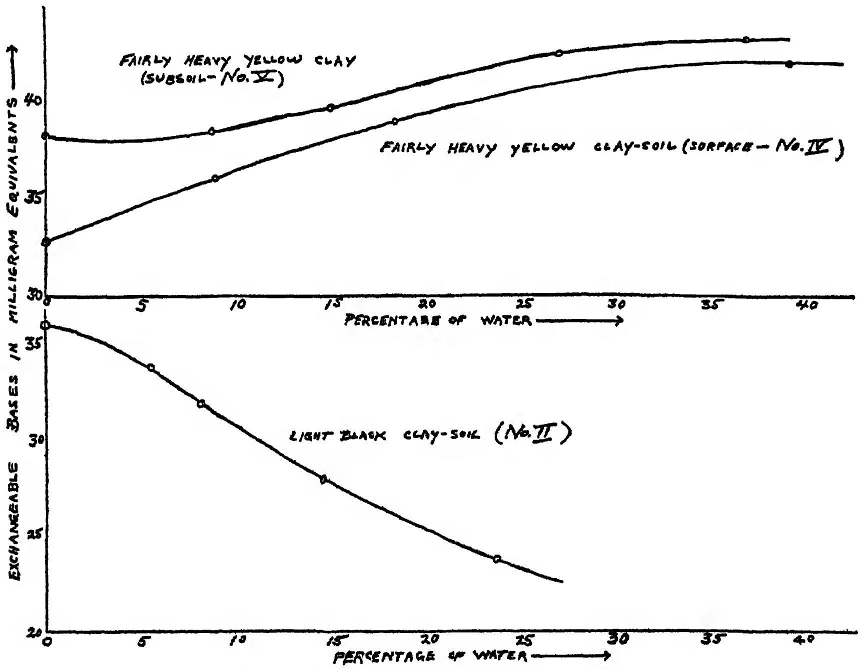


FIG. 2. EFFECT OF DEHYDRATION ON EXCHANGEABLE BASES

cussed later in experiments specially conducted to throw some light on these phenomena (see part II).

Individual exchangeable bases. It now becomes necessary to analyse separately the results obtained for the two sets of soils, which give such divergent results on being dried out, and to see whether certain bases are more affected than others during the drying-out process:

In the first set of soils, I, II, and III give a definite increase of absorbed bases on being dried out. Since the light black clay-soil (II) gives the steepest curve for exchangeable bases against water content, it seems desirable to compare the increase of each individual base with that obtained for soils I and III.

Under conditions varying from more or less the same moisture content to dryness, the increase of calcium for soil II is 7.02 mgm. equivalents compared to 3.63, and 4.60 for soils I and III respectively. The total amount of exchangeable calcium for soil I is 18.26 mgm. equivalents (at 0 per cent water), and for soil II, 25.07 mgm. equivalents, so that soil II not only gives a higher increase, but also contains more exchangeable calcium than soil I. Soil III contains

TABLE 1

Mechanical analyses of soils

TREATMENT	FINE GRAVEL AND COARSE SAND	PERCENTAGE ON WATER-FREE SOIL					
		Moisture	Organic matter	Fine sand	Silt	Fine silt	Clay
Heavy clay soil (III)							
Treated with 0.2 *N* HCl and no NH_4OH (*A*)	11.36	28.58	10.56	18.01	18.24	31.81	12.50
	11.51	23.68	10.56	16.48	19.09	30.09	12.27
	11.12	18.82	10.56	17.68	19.58	29.11	11.95
	11.20	10.42	10.56	17.91	22.99	29.38	9.91
	11.31	0.00	10.56	17.50	22.62	29.37	9.10
0.2 *N* HCl and subsequently NH_4OH (*B*)	11.52	28.58	10.56	10.60	13.04	31.80	18.34
	11.01	23.68	10.56	10.89	14.52	32.16	17.80
	11.72	18.82	10.56	10.92	15.81	33.01	17.45
	12.01	10.42	10.56	10.28	17.16	33.89	16.80
	11.61	0.00	10.56	10.77	19.89	33.87	16.15
No chemicals added (*C*)	11.68	28.58	10.56	10.63	51.12	12.88	7.50
		23.68	10.56	14.53	49.80	12.52	5.80
		18.82	10.56	15.56	47.38	12.15	4.23
		10.42	10.56	24.90	39.50	11.04	3.12
		0.00	10.56	30.90	33.90	10.70	2.26
Organic matter oxidized with H_2O_2 without NH_4OH (*D*)	11.68	28.58	10.56	5.00	36.21	28.95	7.20
		23.68	10.56	7.48	35.41	28.05	6.82
		18.82	10.56	8.74	35.40	27.52	6.19
		10.42	10.56	14.09	33.02	26.96	5.69
		0.00	10.56	16.78	32.59	23.48	4.91
Sandy humus (I)							
H_2O_2 oxidation	70.68	Fresh air-dried	11.03	5.49	4.37	5.78	1.29
			11.03	5.46	4.85	5.94	1.19

slightly more exchangeable calcium than soil II, but gives an increase slightly lower. This soil, however, has a far more pronounced curvature (see fig. 1) than II, and seems, therefore, less normal (see part II).

The largest increase for magnesium is for soil I, giving 0.89 mgm. equivalents compared to 0.45 for soil II, and 0.56 for soil III. Again, however, the total exchangeable magnesium is much larger for soil I than for the other two, being

4.47 mgm. equivalents as compared to 2.83 and 1.73 for soils II and III respectively.

For potassium again the increase is largest for soil II which gives 1.33 mgm. equivalents, whereas I and III give 0.18 and 0.72 respectively. Furthermore soil II contains more exchangeable potassium than the other two, i.e. 1.70 mgm. equivalents compared to 0.58 and 1.53 for I and II, respectively.

Also for sodium there is for soil II, a definite increase which is, like potassium, directly proportional to the amount of exchangeable sodium. Soils II, I, and III show increases of 3.46, 0.08, and 0.42 mgm. equivalents respectively

TABLE 2

Exchangeable bases and degree of saturation of sandy humus-soil (no. 1—containing traces of calcium carbonate) at different water contents

WATER	BASE	PER CENT ON WATER-FREE SOIL			EXCHANGEABLE BASES IN MILLIGRAM EQUIVALENTS	PER CENT EXCHANGEABLE BASES OF TOTAL BASES	ON 100 GM. DRY SOIL IN MILLIGRAM EQUIVALENTS		
		Exchangeable bases	Acid-soluble bases	Total bases (HCl)			$(T-S)$	(S)	$\frac{S}{T}\times 100$
per cent									
21.00	CaO	0.4103	0.2007	0.6110	14.63	67.16	22.50	19.52	46.45
	MgO	0.0721	0.0791	0.1512	3.58	47.67			
	K_2O	0.0190	0.1360	0.1550	0.40	12.26			
	Na_2O	0.0280	0.0802	0.1082	0.90	25.88			
10.01	CaO	0.4723	0.1387	0.6110	16.85	77.31	20.80	22.59	52.06
	MgO	0.0854	0.0658	0.1512	4.24	54.68			
	K_2O	0.0234	0.1316	0.1550	0.50	15.10			
	Na_2O	0.0312	0.0770	0.1082	1.01	28.84			
4.10	CaO	0.4813	0.1297	0.6110	17.16	78.77	17.80	23.75	57.16
	MgO	0.0902	0.0610	0.1512	4.47	59.65			
	K_2O	0.0235	0.1315	0.1550	0.50	15.17			
	Na_2O	0.0501	0.0581	0.1082	1.62	46.30			
0.00	CaO	0.5120	0.1315	0.6110	18.26	83.81	15.00	24.89	62.40
	MgO	0.0901	0.0611	0.1512	4.47	59.58			
	K_2O	0.0255	0.1295	0.1550	0.58	16.45			
	Na_2O	0.0491	0.0591	0.1082	1.58	45.38			

and contain 6.40, 1.58, and 1.23 mgm. equivalents of total exchangeable sodium.

One of the main factors, therefore, causing a big increase in exchangeable bases, when a normal soil is dried out, will be the amount of absorbed bases held by the soil in its moist condition. The more exchangeable bases it contains the bigger will be the increase, as a result of dehydration.

The exchangeable bases for the second set of soils (IV, V, and III b) were determined individually only for soil IV (table 5). The sums of absorbed bases

for the other two (tables 7 and 11, respectively) were estimated by the acid treatment method of Comber (3).

Table 5 shows, despite the comparatively high amounts of the individual exchangeable bases present, a very definite and proportional decrease of absorbed bases the drier the soil becomes. This is obviously also the case with soil V (fig. 2), except for a slight increase near the final stages of dehydration; the same may safely be said of soil III b, since its graph (fig. 1) for the sum of the

TABLE 3

Exchangeable bases and degree of saturation of light black clay-soil (no. II—deficient in calcium carbonate) at different water contents

WATER	BASE	PER CENT ON WATER-FREE SOIL			EXCHANGEABLE BASES IN MILLIGRAM EQUIVALENTS	PER CENT EXCHANGEABLE BASES OF TOTAL BASES	ON 100 GM. DRY SOIL IN MILLIGRAM EQUIVALENTS		
		Exchangeable bases	Acid-soluble bases	Total bases (HCl)			$(T-S)$	(S)	$\frac{S}{T}\times 100$
per cent									
23.5	CaO	0.5061	0.2468	0.7529	18.05	67.23	43 00	23.74	35.59
	MgO	0.0487	0.5273	0.5760	2.38	8.46			
	K_2O	0.0175	0.4574	0.4749	0.37	3.69			
	Na_2O	0.0911	0.1591	0.6992	2.94	13.03			
14.6	CaO	0.5561	0.1968	0.7529	19.84	73.87	41.50	27.94	40.25
	MgO	0.0511	0.5249	0.5760	2.53	8.87			
	K_2O	0.0340	0.4409	0.4749	0.72	7.16			
	Na_2O	0.1503	0.0999	0.6992	4.85	21.50			
8.0	CaO	0.6107	0.1422	0.7529	21.78	81.12	41.30	31.79	44.11
	MgO	0.0560	0.5200	0.5760	2.78	9.72			
	K_2O	0.0578	0.4171	0.4749	1.23	12.17			
	Na_2O	0.1861	0.0641	0.6992	6.00	26.62			
5.5	CaO	0.6521	0.1008	0.7529	23.26	86.62	40.30	33.71	45.54
	MgO	0.0570	0.5190	0.5760	2.83	9.90			
	K_2O	0.0680	0.4069	0.4749	1.44	14.32			
	Na_2O	0.1912	0.0594	0.6992	6.18	27.34			
0.0	CaO	0.7030	0.0499	0.7529	25.07	88.21	38.00	36.00	48.65
	MgO	0.0571	0.5189	0.5760	2.83	9.91			
	K_2O	0.0805	0.3944	0.4749	1.70	16.96			
	Na_2O	0.1985	0.0517	0.6992	6.40	28.39			

exchangeable bases against wetness of soil, is similar to that obtained for soil IV (fig. 2), of which the individual absorbed bases have been determined.

Consequently another factor, which would determine the increase of the bases according to dryness of soil, and which is undoubtedly the cause of the curious behaviour of soils IV, V, and III b now comes into play, namely, the degree of weathering of a soil (see part II). Therefore, the effect of dehydra-

tion on the exchangeable bases for any soil will be determined, on the one hand, by the total amount of absorbed bases held by the soil, and on the other hand, by the degree of weathering of that soil.

Acid-soluble bases. The bases soluble in strong hydrochloric acid were

TABLE 4

Exchangeable bases and degree of saturation of clay-soil (fairly heavy) (no. III—containing calcium carbonate) at different water contents

WATER	BASE	PER CENT ON WATER-FREE SOIL			EXCHANGEABLE BASES IN MILLIGRAM EQUIVALENTS	PER CENT EXCHANGEABLE BASES OF TOTAL BASES	ON 100 GM. DRY SOIL IN MILLIGRAM EQUIVALENTS		
		Exchangeable bases	Acid-soluble bases	Total bases (HCl)			$(T - S)$	(S)	$\frac{S}{T} \times 100$
per cent									
28.54	CaO	0.6510	0.3763	1.0273	23.21	63.39	34.90	25.73	42.16
	MgO	0.0219	0.5144	0.5663	1.09	4.08			
	K_2O	0.0300	0.6211	0.6521	0.64	4.60			
	Na_2O	0.0240	0.2561	0.2801	0.77	8.57			
23.68	CaO	0.6825	0.3448	1.0273	24.34	66.45	34.00	27.32	44.55
	MgO	0.0235	0.5128	0.5663	1.17	4.15			
	K_2O	0.0381	0.6140	0.6521	0.81	5.84			
	Na_2O	0.0250	0.2551	0.2801	0.81	8.92			
18.82	CaO	0.7788	0.2485	1.0273	28.06	75.82	33.10	31.45	48.72
	MgO	0.0278	0.5085	0.5663	1.38	4.91			
	K_2O	0.0490	0.6041	0.6521	1.04	7.52			
	Na_2O	0.0300	0.2501	0.2801	0.97	10.71			
10.42	CaO	0.7910	0.2363	1.0273	28.21	77.02	32.5	32.26	49.82
	MgO	0.0311	0.5052	0.5663	1.54	5.49			
	K_2O	0.0621	0.5900	0.6521	1.32	9.52			
	Na_2O	0.0370	0.2431	0.2801	1.19	13.20			
1.59	CaO	0.8120	0.2153	1.0273	28.96	79.07	28.20	33.36	54.19
	MgO	0.0344	0.5019	0.5663	1.71	6.08			
	K_2O	0.0692	0.5829	0.6521	1.47	10.61			
	Na_2O	0.0380	0.2421	0.2801	1.23	13.56			
0.00	CaO	0.8115	0.2153	1.0273	28.94	79.02	28.10	33.42	54.33
	MgO	0.0348	0.5015	0.5663	1.73	6.49			
	K_2O	0.0720	0.5801	0.6521	1.53	11.04			
	Na_2O	0.380	0.2421	0.2801	1.23	13.56			

determined by the method used in soil analysis (9), and from these figures the acid-soluble bases were obtained in the usual way.

The total amount of each individual base, i.e. the sum of exchangeable and acid-soluble bases, as found by strong HCl extraction, is the same, within experimental error, for the same soil at different stages of dehydration, so that

the average of a duplicate can safely be taken as the amount soluble in strong hydrochloric acid for all water contents of the soil.

This being the case, it is obvious that, if the exchangeable bases increase as a result of drying out of the soil, this increase will take place at the expense of the acid-soluble bases and vice versa (see tables).

Total quantity (T) which soil is capable of absorbing

Now that the method of estimating the quantity of absorbed bases actually present in a soil (S) is known, the only other factor which is necessary to determine the degree of saturation of a soil, is the quantity which the soil is still capable of binding. This is easily found by determining the percentage of unsaturated soil acids $(T - S)$ by means of the conductometric titration method suggested and worked out by Hissink (11).

TABLE 5

Exchangeable bases and degree of saturation of yellow clay-soil (no. IV—deficient in calcium carbonate) at different water-contents

WATER	BASE	PER CENT ON WATER-FREE SOIL			EXCHANGEABLE BASES IN MILLIGRAM EQUIVALENTS	PER CENT EXCHANGEABLE BASES OF TOTAL BASES	ON 100 GM. DRY SOIL IN MILLIGRAM EQUIVALENTS		
		Exchangeable bases	Acid-soluble bases	Total bases (HCl)			$(T - S)$	(S)	$\frac{S}{T} \times 100$
per cent									
39.2	CaO	0.8991	0.1330	1.0320	32.06	87.12	51.00	42.07	45.20
	MgO	0.1603	1.7817	1.9420	7.95	8.25			
	K_2O	0.0403	0.6057	0.6489	0.92	6.65			
	Na_2O	0.0354	0.1482	0.1836	1.14	19.28			
18.20	CaO	0.8390	0.1930	1.0320	29.92	81.30	48.9	39.12	44.40
	MgO	0.1492	1.7930	1.9420	7.40	7.69			
	K_2O	0.0392	0.6097	0.6489	0.83	6.04			
	Na_2O	0.0299	0.1537	0.1836	0.96	16.29			
8.8	CaO	0.7801	0.2520	1.0320	27.83	75.60	49.09	36.17	42.31
	MgO	0.1382	1.8040	1.9420	6.85	7.10			
	K_2O	0.0331	0.6158	0.6489	0.71	5.10			
	Na_2O	0.0235	0.1601	0.1836	0.76	12.80			
0.00	CaO	0.7010	0.3310	1.0320	25.00	67.92	51.89	32.77	38.70
	MgO	0.1309	1.8110	1.9420	6.49	6.74			
	K_2O	0.0313	0.6176	0.6489	0.66	4.82			
	Na_2O	0.0192	0.1644	0.1836	0.62	10.46			

Method. A certain quantity of soil is weighed off in a series of test tubes. Increasing quantities of deci-normal baryta, for instance 5 cc., 10 cc., etc. are added. To each tube is added water to bring the volume to 50 cc. These test tubes are occasionally shaken during the first three days. The contents

of the tubes are than allowed to settle overnight. As it is only the straight part of the baryta line that is wanted, it will be sufficient to analyse the contents of those test tubes in which, on the morning of the fourth day, the supernatant liquid is perfectly clear. Part of this clear liquid is pipetted off, and

TABLE 6

Determination of (T − S) of clay-soil (no. II) at different water-contents

Calculated on 100 gm. water-free soil

WATER	MILLIGRAM EQUIVALENTS BaO ADDED	MILLIGRAM EQUIVALENTS BaO REMAINING IN SOLUTION	MILLIGRAM EQUIVALENTS BaO ABSORBED BY SOIL	S	$T-S$	$V=\frac{S}{T}\times 100$
per cent						
23.5	16.28	Turbid	.....	23.74	43.0	35.59
	32.55	2.61	29.94			
	48.83	11.93	25.69			
	65.10	25.69	39.41			
	81.38	40.52	40.86			
	97.38	55.17	42.48			
	113.93	71.03	42.90			
14.6				27.94	41.5	40.25
7.97	16.28	Turbid	.....	31.79	41.3	44.11
	32.55	2.98	29.57			
	48.83	12.28	36.55			
	65.10	26.34	38.76			
	81.38	40.38	40.85			
	97.38	56.41	41.00			
	113.93	73.01	41.50			
5.5	39.40	1.77	37.63	33.91	40.3	45.54
	59.10	22.14	36.70			
	78.80	40.27	38.53			
	137.90	99.38	38.52			
	157.60	121.10	36.50			
0.0	37.42	5.14	32.28	36.0	38.0	48.65
	56.13	18.28	37.85			
	74.84	37.15	37.69			
	93.55	56.72	36.83			
	112.26	73.43	38.83			
	130.97	92.92	38.05			
	149.68	113.70	35.98			

the BaO determined (table 6). The quantities of baryta which are added are marked off on the horizontal axis, those remaining in solution on the vertical axis. The straight part of the baryta line is then drawn and produced until it intersects the horizontal axis. This point of intersection expressed in milligram equivalents for 100 gm. of soil gives $T-S$ (see fig. 3).

As a preliminary, a mechanical analysis of each soil, in air-dried condition for which $T-S$ was being determined, was made, by the Robinsin method in order to determine how much soil should be taken, so that about 2 gm. clay substance might be tested.

Special precautions were taken in these experiments to test always the same amount of clay substance, i.e. silt + fine silt + clay ($<40\mu$), since the quantity of soil taken influences the results obtained for $T-S$. Experiments were conducted with varying amounts of soil, and only in the case where 2 gm. clay substance were used were the results comparable to other soils, of which also

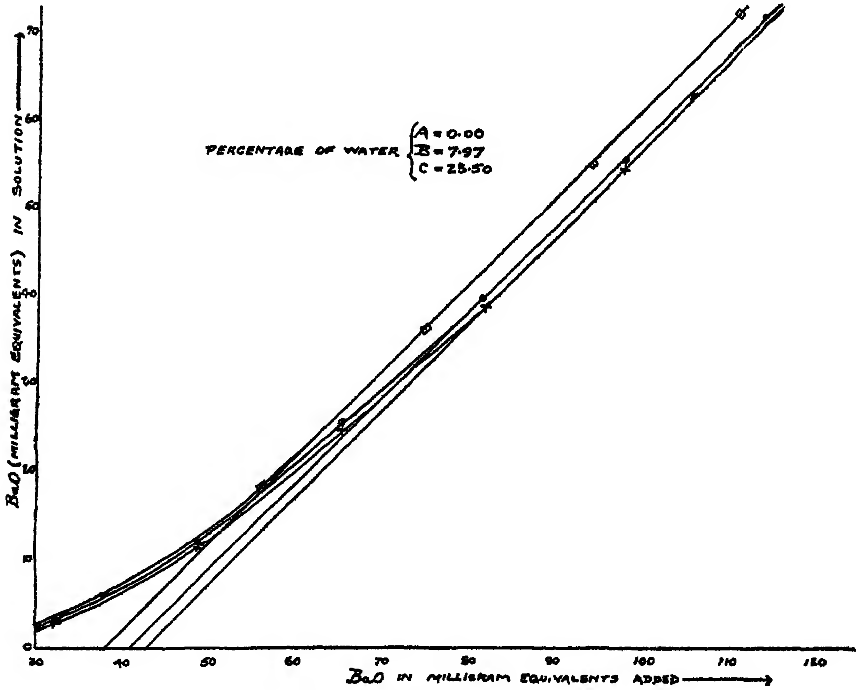


FIG. 3. DETERMINATION OF $T-S$ (HISSINK)

2 gm. clay were tested (see table 7). Five grams of soil IV, i.e. 2 gm. clay substance, gave a figure of 51 mgm. equivalents for $T-S$, whereas 4 and 2 gm. gave 71 and 109 mgm. equivalents, respectively. Figures for quantities larger than 2 gm. clay substance proved similarly incomparable.

The moist and dried-out samples, as a result of the preliminary operation through a 3 mm. sieve, differed very considerably in texture. It was therefore found necessary; in order to equalize and facilitate the slaking effect, to place each set of test tubes, bound with elastic bands, at each water content of the soil into a mechanical shaker, and to shake for some time (say 3 hours). After this operation the test tubes were only shaken occasionally.

After enough water was added to each test tube to bring its contents to 50 cc., the moisture contents of the soils were taken into account each time when titrated, and $T-S$ was reckoned on 100 gm. of dry soil in milligram equivalents.

Experimental. $T-S$ determinations were made for four different soils, the

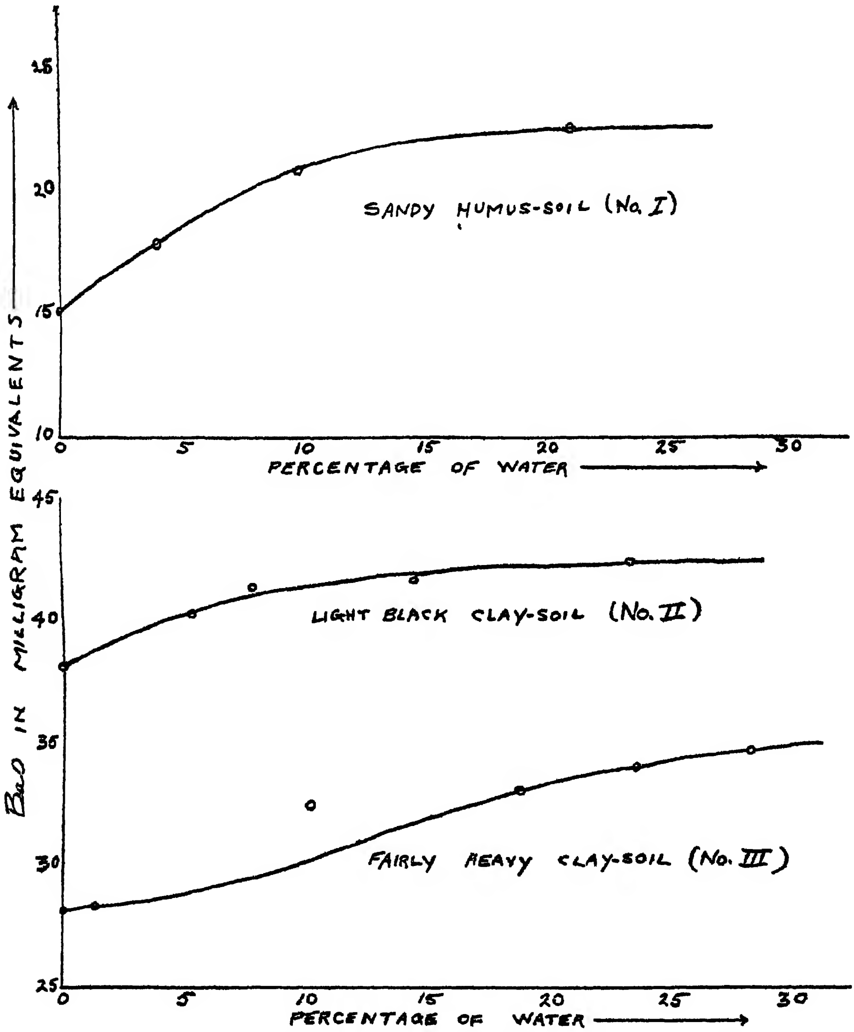


FIG. 4. EFFECT OF DEHYDRATION ON ABSORPTION OF BASES ($T-S$)

results of which are given in tables 2, 3, 4 and 5, respectively; and lime requirements of three other soils (table 7) were reckoned on 100 gm. dry soil in milligram equivalents, according to the Hutchinson-MacLennan (12) method.

It is very interesting to note here, that the three soils, sandy humus (I),

light black clay (II), and fairly heavy clay (III), all three of which give a definite increase in exchangeable bases, give distinct, decreasing values for $T-S$ on being dried out (fig. 4). Soils IV and V, on the other hand, show a steady decrease in absorbed bases according to dryness, whereas the curves obtained for lime requirement (fig. 5) show at the initial stages of dehydration a steady but slow decrease of calcium bicarbonate absorption. In the closing stages of dehydration, the absorption by soil IV (surface) tends to increase slightly beyond the absorption in the moist condition; soil V (subsoil) also gives an increase, but does not reach the amount absorbed in its moist state. Both lime requirement and $T-S$ estimations were made on the yellow clay-soil IV,

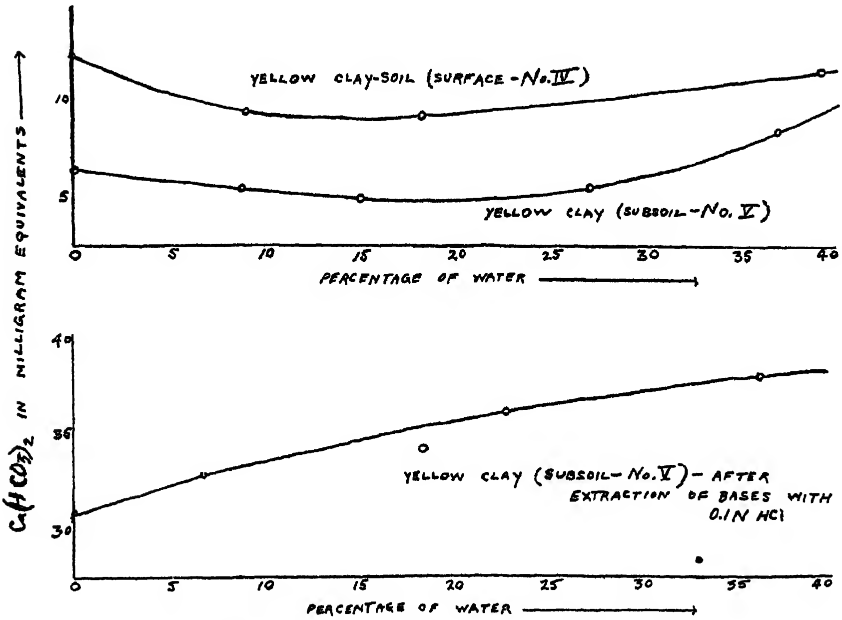


FIG. 5. EFFECT OF DEHYDRATION ON LIME REQUIREMENT

the curves of which were identical. The only difference was that of the magnitude of the figures obtained (see table 7).

The curve showing decrease of the absorption of baryta according to dryness of soil is steepest for the sandy humus (I), especially at the closing stages of dehydration. The light black clay-soil (II) shows a very similar effect, whereas the heavy clay (III) shows a decrease at the initial stages of drying out, but near the closing stages there seems to be a suggestion of more absorption of baryta.

Soils I and II contain very much more organic matter than any of the others, No. I containing slightly more than II. Humus, therefore, seems to be the main cause of the sudden decreased absorption of baryta from an approximately air-dried condition toward total dryness. The heavy clay soil containing a small amount of humus shows a more regular decrease of absorption.

This latter soil, however, may be near the transition from decreased base absorption to increased base absorption, as is definitely illustrated by the curves of soils IV and V, surface and subsoil of yellow clay pasture soil, respec-

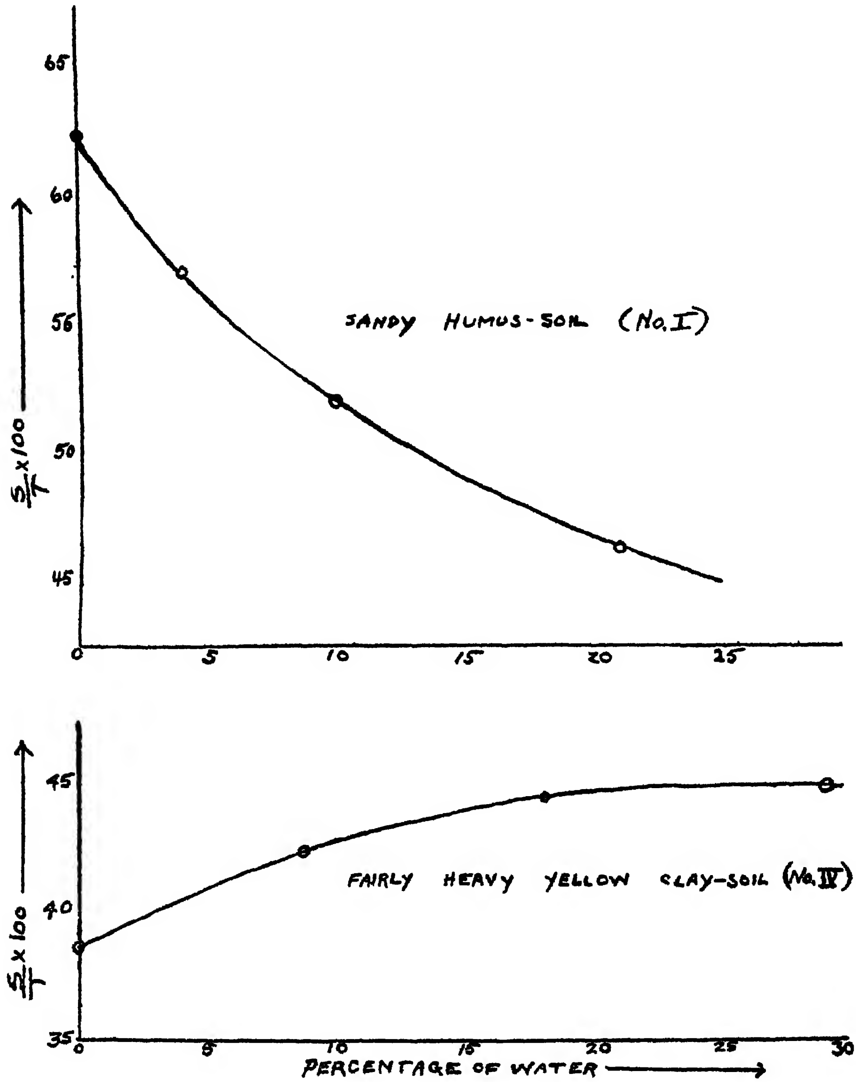


FIG. 6. EFFECT OF DEHYDRATION ON DEGREE OF SATURATION $\left(\frac{S}{T} \times 100\right)$

tively. A comparison of the latter two graphs shows that new absorbing material is created as a result of the drying-out process and that the surface soil is considerably more affected than the subsoil. This point will be referred to later (see part II).

A comparison of the graphs obtained for degree of saturation against moisture content of these soils (figs. 6 and 7) shows that three soils give a definite increase; the fourth, the fairly heavy yellow clay-soil (IV), shows a distinct decrease in the degree of saturation. It will be remembered that this soil also showed results different from the others for exchangeable bases and $T - S$, according to dryness. Of the former three soils the steepest curve for increase is the sandy humus-soil (I), the second steepest being the light black clay-soil (II). The fairly heavy clay-soil (III), which contains very much more clay substance than the other two, although, like both these is also a cultivated soil,

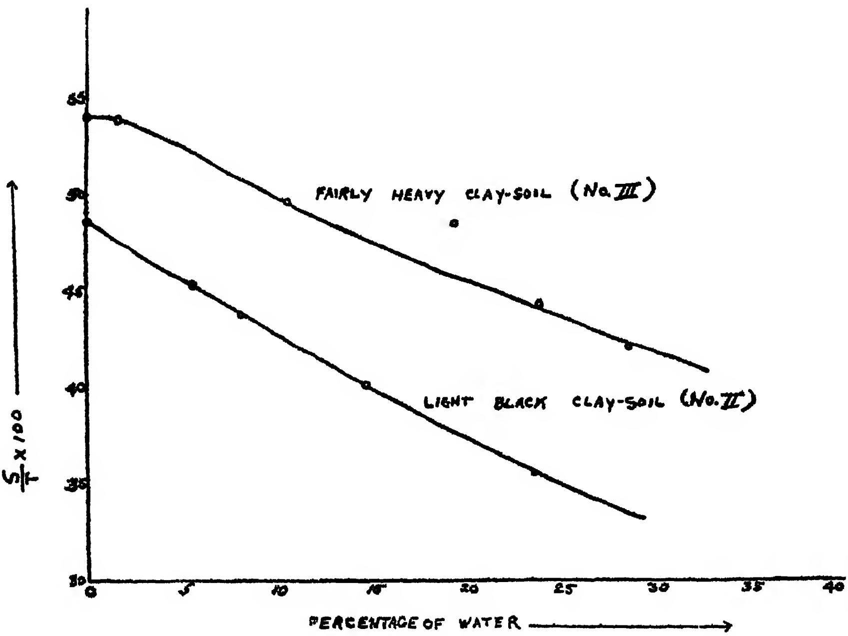


FIG. 7. EFFECT OF DEHYDRATION ON DEGREE OF SATURATION $\left(\frac{S}{T} \times 100\right)$

seems to suggest the beginning of the reverse change toward the graph obtained for fairly heavy yellow pasture soil (fig. 7).

An analysis of the results obtained for these four soils shows that the effect of dehydration on the soil reaction (pH), and on the physical condition would be different for each.

The effect of the sandy humus-soil (I) on the soil reaction should be very much more pronounced than that of the three clay soils, since the increase in its saturation of bases is very much greater and it contains more humus. This soil on being dried out would possibly change from an acid reaction, because of the humus acids, to an alkaline one—at least, one may safely predict a decrease of a possible initial acid reaction to possibly an alkaline reaction when

dry. In the case of the light black clay-soil (II) this effect would be less pronounced both because of the smaller amount of humus present, and also because of the slower increase of saturation with bases, although its initial degree of saturation is very much lower than the sandy humus soil. The yellow clay (IV), because it becomes more unsaturated on being dried out, ought to show a tendency towards an acid reaction, whereas the clay soil (III) should be just the reverse. Clay acids must be dealt with here, however, which are very much weaker than humus acids, so that difference of behavior of these two soils is undoubtedly noticeably less pronounced than may be expected.

It will appear that dehydration can produce two effects; namely, *an increase in the unsaturated clay acids, and an increase in the exchangeable bases present.* This latter effect will tend to counteract the effect of the former. Dehydration of the yellow clay soil IV will, therefore, have a deflocculating tendency, causing bad tilth and difficult cultural conditions. The other soils which give an increase in the degree of saturation will have as a result, a flocculating effect rendering the soil more easy to work.

REFERENCES

(1) Alway, F. J., and Vail, C. E. 1909 *Jour. Indus. and Engin. Chem.*, 1: 74–76.

(2) Buckman, H. O. 1911 Moisture and nitrate relations in dry land agriculture. *Jour. Amer. Soc. Agron.*, 2: 121–138.

(3) Comber, N. M. 1922 The flocculation of soils: III. *Jour. Agri. Sci.*, 12: 374.

(4) Ehrenberg, P. 1915 Die Bodenkolloide. Dresden and Leipzig.

(5) Fischer, E. A. 1924 Remarks and observations on imbibitional soil moisture. *Jour. Agr. Sci.*, 14: 205.

(6) Gustafson, A. F. 1922 The effect of drying on the water-soluble constituents. *Soil. Sci.*, 13: 173–213.

(7) Hardy, F. 1923 The physical significance of the shrinkage coefficient of clays and soils. *Jour. Agr. Sci.*, 13:

(8) Hilgard, E. W. 1911 Soils, 61–389. New York.

(9) Hissink, D. J. 1915 Ueber die Bedeuting und die Methode der chemischen Bodenanalyse mit starker heiszer Salzsäure. *Internatl. Mitt. Bodenk.*, 5: 1–24.

(10) Hissink, D. J. 1922 Beitrag zur Kenntnis der Adsorptions-vorgänge im Boden. *Internatl. Mitt. Bodenk.*, 12: 81–172.

(11) Hissink, D. J. 1922 Base exchange in soils. *Trans. Faraday Soc.* (December): 560–562.

(12) Hutchinson, H. B., and MacLennan, K. 1915 Studies on the lime requirements of certain soils. *Jour. Agr. Sci.*, 7: 75.

(13) Kelley, W. P., and McGeorge, W. 1913 The effect of heat on Hawaiian soils Hawaii Agr. Exp. Sta. Bul. 30.

(14) Lebedjantzev, A. N. 1924 Drying of soil as one of the natural factors in maintaining soil fertility. *Soil Sci.*, 18: 419–447.

(15) Lyon, T. L., and Bizzell, J. A. 1913 Some relations of certain plants to the formation of nitrates in soils. N. Y. (Cornell) Agr. Exp. Sta. Mem. 1.

(16) Robinson, G. W. 1922 A new method for the mechanical analysis of soils and other dispersions. *Jour. Agr. Sci.*, 12: 306–321.

(17) Robinson, G. W. 1922 Note on the mechanical analysis of humus soils. *Jour. Agr. Sci.*, 12: 287–291.

(18) Tempany, H. A. 1917 The shrinkage of soils. *Jour. Agr. Sci.*, 8: 312–330

SOIL TEMPERATURES IN SASKATCHEWAN

E. L. HARRINGTON

University of Saskatchewan

Received for publication September 27, 1927

During the years 1921 to 1923, inclusive, the late Professor McGougan directed an experimental investigation of the question of temperature variations at different depths below the surface of the ground. Unfortunately, ill health and other circumstances delayed the writing of a report on this work, and his death came before any written account of the work was prepared. A disastrous fire, which burned the engineering building, destroyed also the records of the observations, and part of the equipment used in this investigation. Fortunately curves had been plotted showing the variations in temperature at the various depths.[1] These really include all that is essential for a report, since they tell the story as well as the detailed records could, and in a more interesting way. These curves, then, supplemented by the points remembered by the writer and certain others who had more or less contact with the work must form the basis of this report. Particular mention should be made of Prof. A. R. Greig, who was in close touch with the work during its progress and of considerable assistance at that time as well as in the writing of this account of the work. It should be understood that the writer makes no claim whatever to any part of the work, and has undertaken this account of it only because he feels that it is due to the memory of the one who directed the work, and because the many inquiries as to the results have indicated the importance of the observations and left no doubt as to the desirability of getting the results into published form. He is fully aware of the fact that a great deal of work has been done, and reports have been published on various problems dealing with soil temperatures, but he has learned of no work of which the present could be considered a duplication.

Only a few investigations by others on the general question of soil temperatures need be mentioned in this report. Some of the articles cited contain bibliographies sufficiently complete to meet the requirements of anyone desiring to make a definite study of the subject.

A rather extended series of observations on soil temperatures was carried out by Callendar and McLeod (4, 5, 6, 8) at McGill University. They used platinum wire resistance thermometers, placed at various depths, the lowest

[1] Thanks are due Mr. L. L. Cunningham to whom was given the duty of making the records and keeping the equipment in proper order, and whose timely drawing of the curves saved the results of the work from loss by fire.

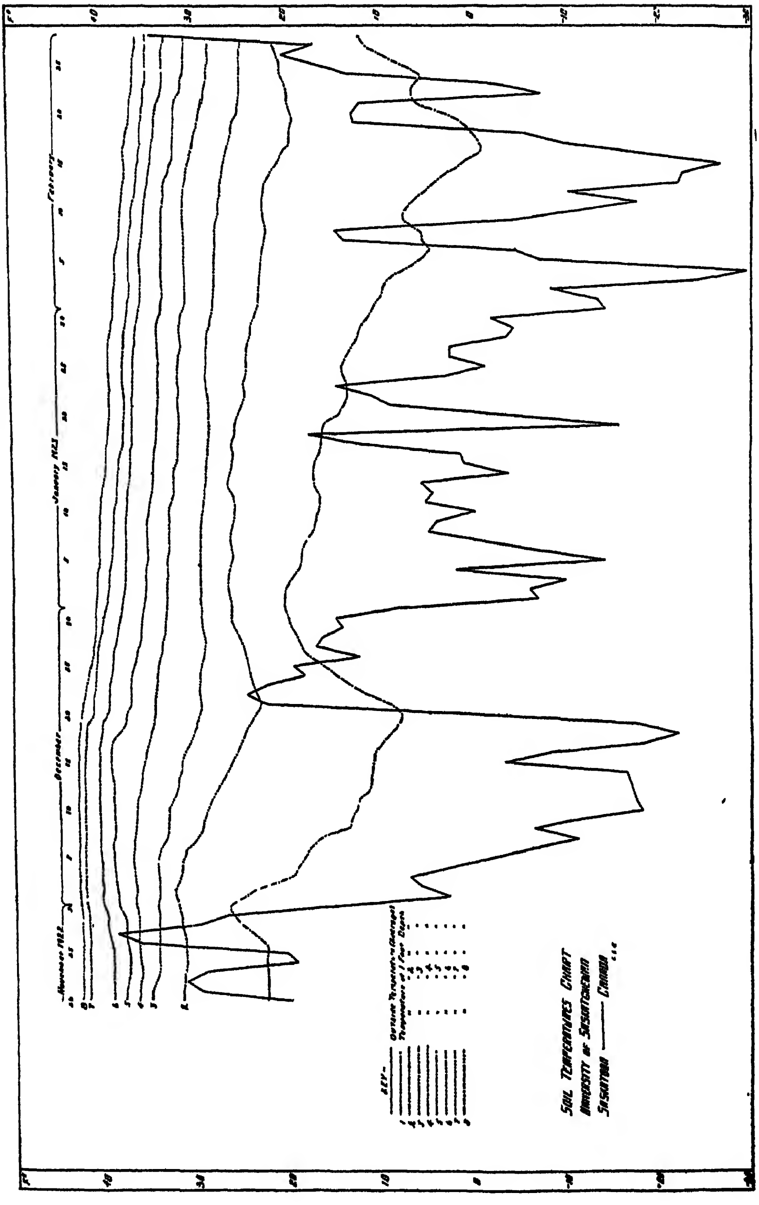


FIG. 1. SOIL TEMPERATURES AT DEPTHS OF 1 TO 8 FEET AND OUTSIDE AIR TEMPERATURES FROM NOVEMBER 20, 1922, TO FEBRUARY 28, 1923

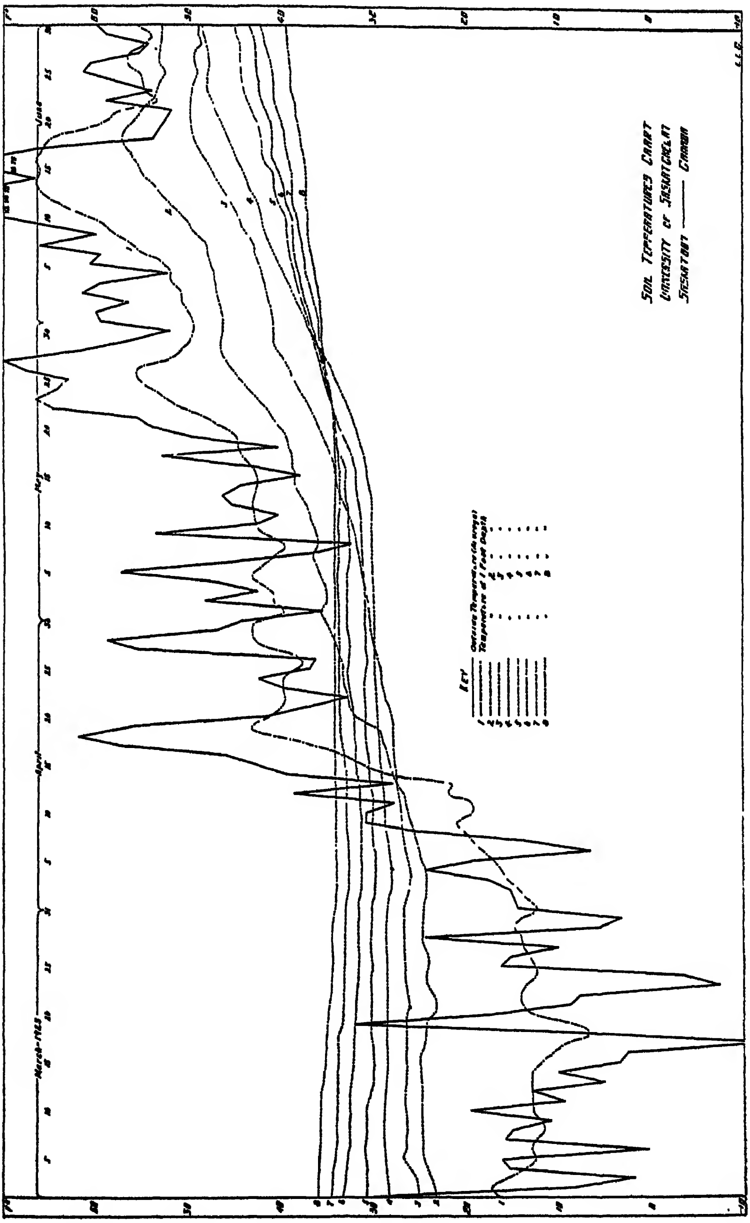


FIG. 2. SOIL TEMPERATURES AT DEPTHS OF 1 TO 8 FEET AND OUTSIDE AIR TEMPERATURES FROM MARCH 1 TO JUNE 30, 1923

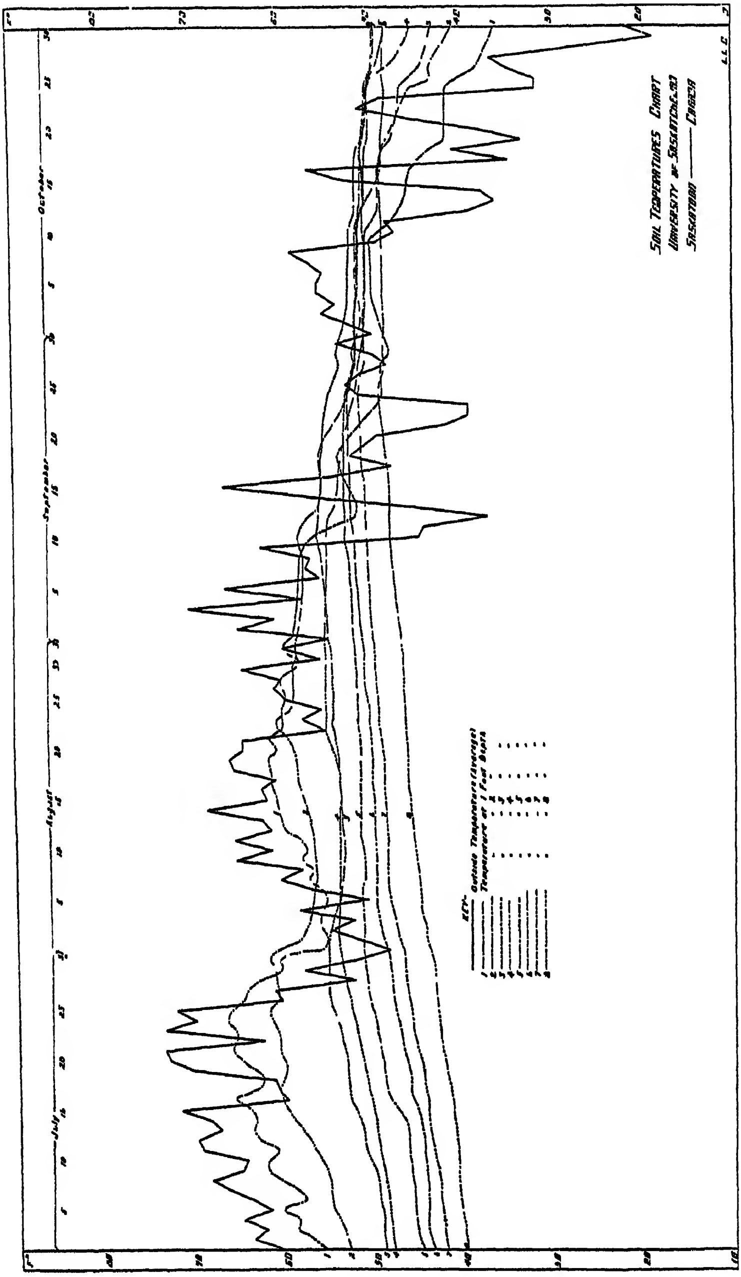


FIG. 3. SOIL TEMPERATURES AT DEPTHS OF 1 TO 8 FEET AND OUTSIDE AIR TEMPERATURES FROM JULY 1 TO OCTOBER 30, 192

being at 9 feet, the next at 5 feet 6 inches, and the others at 40, 20, 10, and 4 inches, respectively. A special study was made of the various conditions affecting soil temperature and particular attention was given to the question of the thermal diffusivity of the soil.

Swezey (9) made observations continuously for a period of twelve years just prior to his report of the temperatures, at depths of 1 inch, 3 inches, 6 inches, 9 inches, 1 foot, 2 feet, and 3 feet. He used soil thermometers, placed at the depths indicated. In the first half of this period the thermometers were read three or four times a day, and in the latter part only once a day.

Bouyoucos (1) made extensive studies of the factors influencing the temperature of the soil, but so far as this report shows, his series were carried out in a laboratory manner for studying specific factors, rather than for making observations under natural soil conditions. A report on additional work of the same sort was made in 1915 (2). His 1916 report (3) dealt more specifically with the question of temperature variations at different depths for different kinds of soils and represented observations continued over a considerable period of time. This is a most valuable contribution to the problem, but again the scope is quite different from that of the work to be described in the present report.

McColloch and Hayes (7) carried out a series of observations more like those made here than any others of which the writer has seen any account. They employed mercury thermometers which were lowered to the bottoms of 1½-inch auger holes varying from 1 foot to 6 feet in depth. Although the location of their work (Manhattan, Kansas), and the methods employed were quite different, the forms of the curves obtained are very similar to those shown in figures 1, 2 and 3.

Tsi-Tung Li (10) has recently reported on the influence of forest and also of herbaceous vegetation covers on soil temperatures. His report includes a considerable discussion of the work done by others along similar lines.

EXPERIMENTAL METHOD

For obtaining the temperature records nickel resistance thermometers used in connection with a Leeds and Northrup recorder were employed. Eight thermometers were buried at depths varying integrally from 1 foot to 8 feet. The temperatures indicated by the various thermometers were automatically recorded daily, throughout the period of more than a year during which the work was continued. The thermometers were duly checked with a standard thermometer and found to be highly accurate. The obvious advantages of this arrangement include the possibility of making all observations indoors and of allowing the thermometers to remain undisturbed throughout the course of the observations. Methods which involve the use of soil thermometers or the lowering of mercury thermometers into holes of varying depths are bound to introduce uncertainties, and they cannot furnish continuous records.

The method of placing the thermometers is important. A hole, sufficiently large in cross section to give a man working room, was dug to a point below the 8-foot line. At levels of 1 foot, 2 feet, etc., horizontal holes were bored with a small auger to a distance of 2 feet from the main hole. Into these the thermometers, protected by waterproof lead sheathing, were inserted and the holes again filled, each with the same soil that had been removed from it. The entire set of wires were carried in waterproof tubing to the recording instrument which was located in the Engineering Building in a position about 100 feet from the thermometers. It is evident that this method of installing the thermometers left the ground above and below the individual thermometers entirely undisturbed, a most important condition which could not be obtained by any method involving the boring of vertical holes. After the installation and tests of the thermometers, the main hole was filled, the soil being well tamped as it was replaced. The whole arrangement was left undisturbed about two years before the observations, represented by the accompanying curves, were recorded. These precautions having been taken, it is highly probable that the results obtained actually represent the temperature variations which took place beneath the surface of the ground at the depths indicated.

The spot chosen was well removed from any buildings, practically free from vegetation, and devoid of wind breaks. In view of the possible influence of the nature of the soil upon its temperature a continuous sample 8 feet 6 inches in depth was taken. Professor F. H. Edmunds, of the soils department of the University of Saskatchewan, very kindly made an examination of this sample and submitted the following report on it:

This soil is typical of a considerable area on the east side of the Saskatchewan river near Saskatoon, the surface consisting of heavy material, clay loam[3] in texture, with calcareous clays below. It is of glacial origin, stones and gravel brought from the northeast in glacial times having been incorporated with the original weathered clays of the prairie. But few stones were found in the profile described, nor are they common in the soil of the immediate vicinity.

Description

Depth of sample *inches*	
0–6	Dark brown clay loam, with high silt content, rich in organic matter and containing a trace of calcium carbonate.
6–18	Dark grayish brown clay, calcium carbonate is abundant as white crumbs, which are clearly visible. A small percentage of gravel is present.
18–30	Dark grayish brown clay, calcium carbonate abundant.
30–42	Dark olive drab clay, with abundant calcium carbonate and occasional crystals of sodium sulfate.
42–54	Olive gray calcareous clay.

[3] The textures clay loam and clay were those established by the United States Bureau of Soils. *Clay loam* contains from 20 to 30 per cent of clay and over 50 per cent silt and clay, under 50 per cent silt. *Clay* contains over 30 per cent clay and over 50 per cent silt and clay.

54–66 Olive gray calcareous clay with white mottlings which consist of small irregular pockets of incipient crystals of calcium sulfate (gypsum).
66–78 Dark olive drab calcareous clay with occasional white mottlings.
78–80 Dark olive drab calcareous clay, with small regular pockets of sand, the grains of which consist entirely of gypsum.
80 92 Olive gray calcareous clay with pockets of gypsum sand.

PLOTTING OF CURVES

The temperature variation curves shown in figures 1, 2 and 3 were made by plotting the mean daily temperatures of the outdoor air, and of the soil at the various depths indicated. Perhaps the most striking thing shown by the curves is the contrast between the steadiness of the temperature at the 8-foot level and that at the surface. The former is entirely unaffected by the daily fluctuations in the latter and during this particular year never rose higher than 49.3°F. nor fell lower than 34.2°. For three months, beginning early in March, it stayed within one degree of 35°F., a most remarkable constancy when one considers the fact that the air temperature varied more than eighty degrees during the same period. There is a similar constant period for this level beginning in September.

The 1-foot level, on the contrary, responds quickly to changes in the air principally because of two factors, its nearness to the surface, and the fluctuations in moisture content. In summer the changes in the atmospheric temperature are followed by similar changes at the 1-foot level approximately one day later. The 2-foot level reflects these same variations, to a lesser degree, with an additional lag of the same amount, pointing to a uniform conductivity within this region. Below the 3-foot level the effects of daily atmospheric fluctuations are difficult to identify, and only the most marked variations show as far as the 5-foot level. In winter when the ground is covered with snow, the lag at the 1-foot level is much greater. In fact in December and January one can scarcely detect any response to the most decided fluctuations in the temperature of the air. This constitutes a most striking evidence of the marked insulating property of snow.

The curves also illustrate what is generally known as the "overturn" in soil temperatures. For the year under observation the temperature at the 1-foot level was above that at the 2-foot level for practically 6 months, or from April 14 to October 10. For the rest of the year the lower level had the higher temperature. The date of the overturn, however, depends upon the depth considered, and in the spring of 1923 the process of reversing the temperature gradients throughout the 8 feet under observation required about six weeks, or the time from April 14 to May 27. The temperature range for the entire group of curves, omitting the air temperature curve, shows one minimum on April 16, and another on October 10. These dates might well be considered as the days on which the group overturns took place.

By way of comparison it is interesting to note that the periods between the overturns in Saskatchewan were practically the same as the corresponding periods in Kansas, as shown by the McColloch and Hayes curves (7, p. 34) though of course all the temperatures were lower in Saskatchewan. It is also observed that at the 6-foot level, the lowest given in the Kansas report, the annual temperature range for Saskatchewan was 21.5°F. and in Kansas it was 28.5°, whereas at the 1-foot level the ranges were 67.5° and 52°, respectively. This apparent inconsistency is explained by the fact that in Saskatchewan the temperature goes to greater extremes, as indicated by the 1-foot curves, whereas the general swings as indicated by the 6-foot temperature curves, which are unaffected by weather fluctuations, indicate a substantially greater uniformity in mean temperatures.

The curves indicate that the frost penetrated to a depth of more than 6 feet, and although this may be taken as a typical case, it must be understood that the depth reached by the frost line is largely controlled by such factors as the depth of snow, the character and amount of vegetation, to a slight extent by the kind and texture of the soil, and finally by the severity and duration of the winter.

The times of occurrence for the minimum temperatures for the different depths vary widely. The curve for the 1-foot depth shows a number of minima because of its ready response to weather changes, but its lowest point is reached on February 16. On the other hand the 8-foot curve remained at its minimum throughout April and the first half of May. A water pipe, then, buried at this depth would reach its lowest temperature at this time rather than in midwinter. This conclusion is quite in line with the experience in city water systems in this climate.

The relations between temperatures, depths, and times of the year are shown perhaps more clearly by the groups of temperature gradient curves given in figures 4 and 5. For the sake of compactness the vertical scales for the successive curves overlap, so they are left unlabelled. However, the vertical scale is uniform throughout, one space representing 10°F. and each line is an integral multiple of 10. The vertical shift for each successive curve is 20°F. As the temperature for the 1-foot depth is indicated in each case, the values for the other depths may be thereby ascertained. For example, the curve for November 30 runs from 26.4° to 43°F. For the first five curves of figure 4 the cross marks give the values for the corresponding dates in 1920. It may be observed in passing that the greatest differences in the two sets of values occur at the shallow depths, and it is interesting to note that by December 30 the two sets of values agree throughout.

Other things being equal the flow of heat at any depth will be proportional to the slope of the curve at that depth, and will of course be toward the lower temperatures. Thus it is seen that from October to April the heat flows toward the surface and is given up to the air, whereas during the remaining part of the year, that is until the fall overturn, the heat flows from the surface downward, only to return the following winter.

As would be expected, the greatest fluctuations in the temperature gradients, and also the steepest gradients are found within the first few feet from the surface of the ground, because of the effect of weather changes. The abrupt change in slope between April 10 and April 20 shows in a graphic way a quick

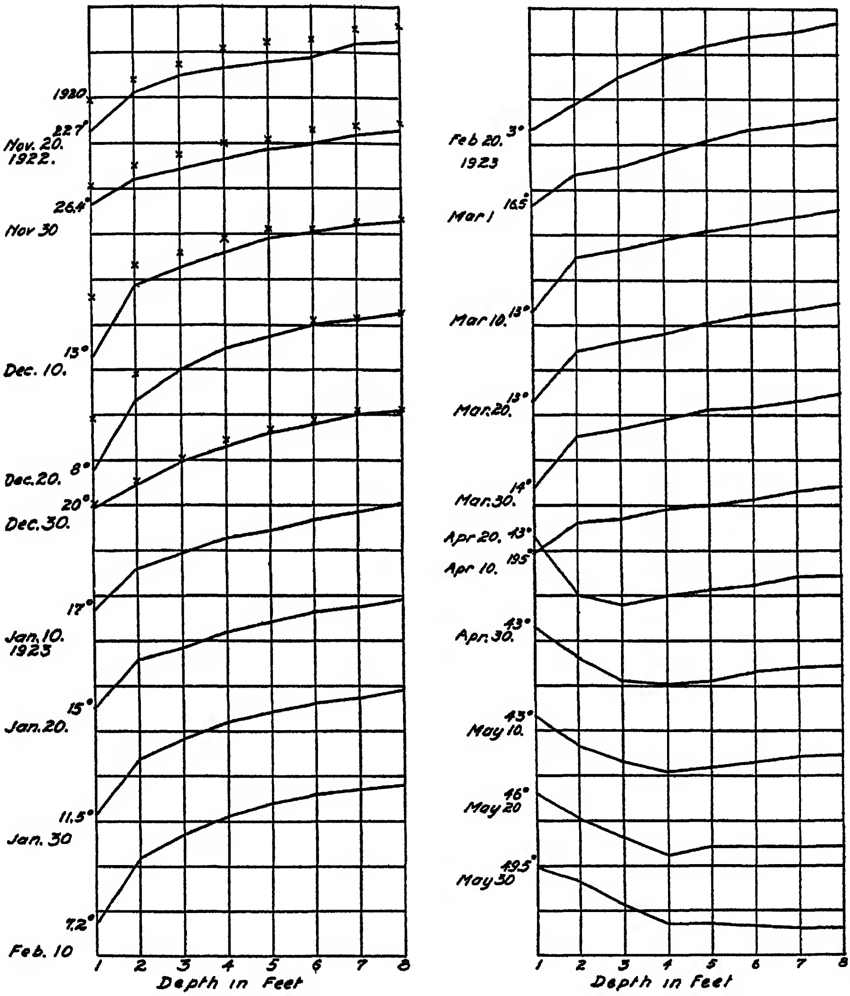


Fig. 4. Temperature Gradients from November 20 to May 30, 1922–23, Showing Relations Between Temperatures, Depths, and Times of the Year

change from winter to spring, something which frequently occurs in this part of the country. The April 20 curve exhibits both positive and negative gradient portions, with a distinct minimum at the 3-foot depth. This means that the heat flows from both directions toward this level; but as the heat from the surface flows more rapidly, the minimum point moves toward greater

depths, and becomes less defined as it moves. The next curve shows this minimum at the 4-foot level. It is not until late May that the gradient becomes negative throughout. In other words, these curves show, just as was observed in connection with the other set of curves, that it requires a consider-

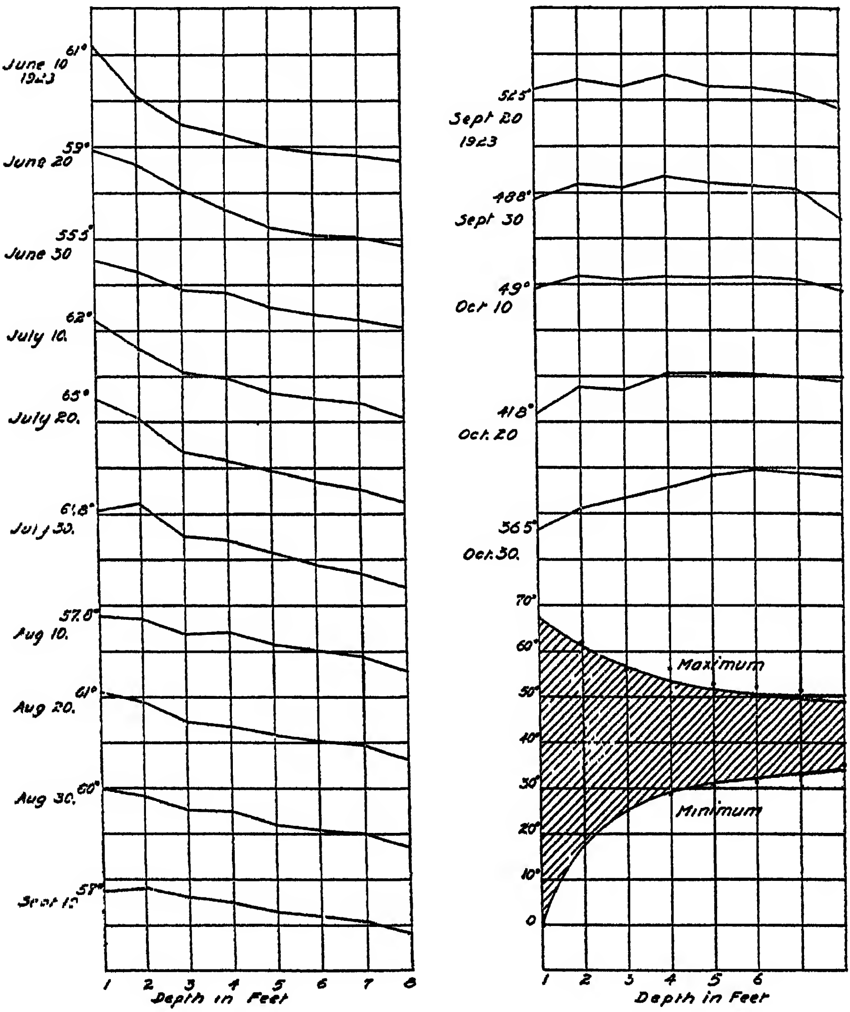


FIG. 5. TEMPERATURE GRADIENTS FROM JUNE 10 TO OCTOBER 30, 1923, SHOWING RELATIONS BETWEEN TEMPERATURES, DEPTHS, AND TIMES OF THE YEAR

able time for the overturn to be completed. The curves for the fall overturn show a much more gradual shift from the negative to the positive gradient. In fact the October 10 curve is almost horizontal, and the temperature at the 1-foot level is the same as that at the 8-foot level.

Although somewhat of a digression, an important significance of these overturns should be mentioned at this point. McColloch and Hayes (7) observed that the spring and fall migrations of the white grubs occurred at exactly the times of the overturns; in other words, the grubs moved downward at the fall overturn and did not return until the spring overturn. Although the possibility of this being a mere coincidence makes additional observations of this type desirable, it is quite possible, and indeed probable, that the grubs take these overturns as their cues for their movements, moving downward when the gradient is positive in that direction, and upward when the gradient reverses, on each occasion moving toward warmer soil. If this could be established as a fact it would have an important bearing on the question of pest control, as observations of the times of overturn would make it possible to time properly the fall plowing in order to make it most effective in pest destruction (7).

The maximum and minimum curves shown in figure 5B indicate the amplitude of the annual temperature variations at the different depths. As would be expected theoretically, the two curves approach each other asymptotically, and while it would be difficult to estimate the depth at which the amplitude would be less than, say five degrees, it is certain that the annual temperature fluctuations do affect the crust of the earth to a far greater depth than 8 feet, the greatest depth included in this investigation.

Bouyoucos (3, p. 101) found that the diurnal-nocturnal fluctuations followed the geometrical progression law and were expressible by the formula $A = FR^{n-1}$ where A is the amplitude, F the first fluctuation, R the ratio of any amplitude (except the first) to the preceding one, and n the number of the amplitude. But the annual fluctuation amplitudes here observed do not follow this law, as R is found to vary at least forty per cent within the range of the depths studied, and the variation is of complex nature. This fact makes it impossible to calculate the amplitude for any greater depth, though by extrapolation the values for slightly greater depths may be estimated.

It is highly significant that the common temperature approached by these maximum and minimum curves is considerably above the mean of the extremes for the 1-foot level. A complete explanation might involve many factors, but at least two should be mentioned. For one thing, it indicates that the extreme low temperatures are less sustained than the higher ones, contrary to general opinion. For another, it indicates that the ultimate common temperature point is raised by the outflow of heat from the interior of the earth. This outward flow of heat is probably of considerable importance in this country, as it delays the winter, accelerates the warming of the ground in the spring, and lessens to an indeterminate degree the depth of frost penetration. Another factor of considerable importance is the latent heat of fusion of ice, since when once the freezing point is reached at any level, further progress of the frost line is limited by the necessity of losing 80 calories of heat for every

gram of water frozen. Were it not for this factor alone, it would be difficult to estimate how deep the frost would penetrate in this country.

For a general discussion of the many factors which have to do with soil temperatures one should consult the bulletins by Bouyoucos (1, 2, 3). For the purpose of this report, it is sufficient to observe that since the primary control of the soil temperatures is vested in the meteorological elements, particularly air temperature, man has power to exercise scarcely any appreciable control under field conditions. He can (*a*) arrange for proper drainage, (*b*) darken the color somewhat, (*c*) cover with a thin layer of sand, (*d*) provide vegetation to hold snow or (*e*) compact the surface of the soil and thereby accelerate the warming in the spring, but the total result of such efforts would be relatively small. A covering of straw during the winter would prevent low extreme in soil temperature and thereby indirectly assist in the spring warming, provided the straw were burned or otherwise removed at the proper time in the spring. The most that man can do is to understand the nature of the soil temperature variations, as, for example, are shown by figures 1 to 5, and to time his plowing and mulch controls in such a way that he makes the best of the situation over which he has so little control.

REFERENCES

(1) Bouyoucos, G. J. 1913 An investigation of soil temperature and some of the most influential factors influencing it. Mich. Agr. Exp. Sta. Tech. Bul. 17.
(2) Bouyoucos, G. J. 1915 Effect of temperature on some of the most important physical processes in soils. Mich. Agr. Exp. Sta. Tech. Bul. 22.
(3) Bouyoucos, G. J. 1916 Soil temperatures. Mich. Agr. Exp. Sta. Tech. Bul. 26.
(4) Callendar, H. L. 1895 Preliminary results of observations of soil temperature with electrical resistance thermometers made at the McDonald Physics Building, McGill University, Montreal. *Trans. Roy. Soc. Canada* 1895 (Sec. III): 63.
(5) Callendar, H. L., and McLeod, C. H. 1896 Observations of soil temperatures with electrical resistance thermometers. *Trans. Roy. Soc. Canada* 1896 (Sec. III): 109.
(6) Callendar, H. L., and McLeod, C. H. 1897 Observations of soil temperatures with electrical resistance thermometers. *Trans. Roy. Soc. Canada* 1897 (Sec. III): 31.
(7) McColloch and Hayes 1923 Soil temperature and its influence on white grub activities. *Ecology* 4: 29.
(8) McLeod, C. H. 1901 Soil temperature observations with electrical resistance thermometers at McGill College, Montreal. *Trans. Roy. Soc. Canada* 1901 (Sec. III): 13.
(9) Swezey, G. D. 1903 Nebr. Agr. Exp. Sta. Ann. Rpt. 95–102.
(10) Tsi-Tung Li. School of Forestry, Yale Univ. Bul. 18.

THE FIXATION OF NITROGEN BY BACTERIUM AEROGENES AND RELATED SPECIES

C. E. SKINNER

University of Minnesota[1]

Received for publication November 4, 1927

In 1924 in the course of experiments with several strains of the coli-aerogenes group isolated from sewage, it was found that *Bacterium aerogenes* (Escherich) Chester developed sufficiently to produce a turbidity in Koser's media (17), even though the uric acid was omitted, thus growing in media practically free from nitrogen, whereas the *Bacterium coli* (Escherich) L. & N. strains showed no such growth. *B. aerogenes* was found to grow also in Ashby's solution and in a similar medium with glucose substituted for mannitol. Only nitrogen-free water and C.P. chemicals were used.

Although no chemical analyses were made, it was thought at the time that there was a probability of nitrogen fixation but due to the pressure of other work, nothing further was done. Meanwhile a few scattered references to nitrogen fixation by this group of organisms have been found in the literature.

HISTORICAL

Before Winogradsky (29) had discovered that the organism which he called *Clostridium pastorianum* fixed nitrogen, Bertholet (5) had announced the isolation of several micro-organisms which he claimed were able to utilize free nitrogen, among them one which, according to Fischer (11), might have belonged to the aerogenes group of bacteria. However, the fact that Bertholet also claimed that two common fungi, *Aspergillus niger* and *Alteraria tenuis*, were able to fix nitrogen—organisms which we now know do not do so—, and the fact that the descriptions were so inadequate lessen the value of his contribution considerably. It is very evident to one reading Bertholet's papers that there is no adequate reason for not giving Winogradsky the credit for first isolating nitrogen-fixing organisms.

Beijerinck and van Delden (3) in 1902 noted that *B. aerogenes* and *Bacterium radiobacter* (Beij) L. & N. acted in symbiosis with *Azotobacter*, and suggested that these two organisms might also act in symbiosis with algae. They always found these bacteria in crude cultures of nitrogen-fixing organism. However, they say—"Dagegen kann Aërogenes an und für sich den freien Stickstoff sicher nicht binden." They placed *B. aerogenes* in the recently described genus, *Aerobacter*.

Lipman (19, 20), however, noted in pure cultures of two gas-forming organisms, which were very probably of this group, that "a slight but unmistakable [nitrogen] fixing power" was evinced. This was contrary to Beijerinck's findings. Like Beijerinck, he noted the presence of these gas-forming bacilli as common contaminants or symbionts in *Azotobacter* crude cultures. He also found that these organisms caused an additional fixation of nitrogen when inoculated together with several species of *Azotobacter* in solution culture.

---

[1] Department of Bacteriology and Immunology.

Lohnis (21) and his associate Pillai (23, 24) have made the most complete investigations of these organisms. It is unfortunate that these studies have been ignored by most British and American writers. Possibly because of a misunderstanding of the nature of *Bacterium pneumoniae* (Friedländer) L. & N.,[2] they were inclined to consider the cultures used by Beijerinck as Friedlander's bacilli, or at least to consider them as very closely related. Contrary to a general impression, at least in America, the type strain of Friedlander's bacillus does not ferment lactose with gas evolution (28). Thus this organism does not belong to the coli-aerogenes group. Undoubtedly this whole group of capsulated or slime-producing gas-forming bacilli needs thorough laboratory taxonomic study. Since Lohnis' cultures formed gas from milk, it is best to consider them as *B. aerogenes*.

Lohnis showed that *B. aerogenes* (*B. pneumoniae*), as well as *B. radiobacter* undoubtedly fixed nitrogen, and noted the cultural variability of different strains of these organisms. He also isolated gas-forming strains of *B. radiobacter*, which undoubtedly most people would routinely put with the coli-typhoid group, as well as a gram-positive, non-spore forming gas-producing organism, all of which used free nitrogen. The common occurrence of gas-producing and slime-forming bacteria in crude nitrogen fixing cultures was again noticed. He emphasized the great similarity between *Bacterium radicicola* and *B. radiobacter* on the one hand, two organisms extremely difficult to separate on media, and *B. radiobacter* with its varieties and *B. aerogenes* on the other, and showed that all intergradations exist. More recently (22) he has very justly criticised the American Society (4) classification for separating *B. radicicola* from its close relative *B. aerogenes*, and putting it among the Nitrobacteriaceae, autotrophic bacteria, the last place one would expect to find a facultative parasite.

Fischer (11, 12) noted that the bacteria *B. radiobactor* and *B. aerogenes*, and algae often occur together. He thought that these two bacteria worked with algae in symbiotic relationship in the nitrogen fixation process and found experimentally that such fixation actually took place. An attempt was made to divide the *B. aerogenes* group, making four strains of *Aerobacter* separate from "*Bacterium lactis aerogenes*," which of course is unjustified since *Aerobacter aerogenes* (Escherich) Beij. is the type species for those who wish to maintain this genus (4,8). Fixation from pure cultures of these gas-producing organisms was also noted. Fischer also stressed the close relationship between these gas-forming organisms and *B. radiobacter*.

Richard (25) has noted the appearance of *B. aerogenes* in impure cultures of *Azotobacter*, and found experimentally that more nitrogen was fixed when *B. aerogenes* was used with *Azotobacter* as an inoculum than when the *Azotobacter* was used alone. Richards apparently was unaware of most of the previous work in this connection.

From this brief review of the literature it would seem that *B. aerogenes* is able to fix atmospheric nitrogen. However, confirmation of these findings and further work seem desirable. Also, although the researches cited seem to be carefully done, it must be confessed that there are many unconvincing experiments reported in the literature regarding nitrogen fixation by organisms other than the so-called *C. pastorianum* and *Azotobacter* species. In fact, the

[2] Weldin (28) is mistaken in his contention that *Bacterium pneumoniae* is invalid as a binomial for Friedländer's bacillus because of the earlier use of that combination for the pneumococcus. Inasmuch as the combination *Bacterium pneumoniae*, as applied to the pneumococcus, has been universally dropped, according to the International Rules, Art. 50, Sec. 7 (8), it is valid for the pneumobacillus, which combination seems to have been made by Lehmann and Neumann in 1896. This is in accordance with the interpretation of the rules which is followed generally. Thus *Bacterium Friedlander* (Friedländer) Weldin is invalid for those who maintain the Lehmann and Neumann concept of *Bacterium* for non-spore forming rods, or for any others who follow International Rules.

critical work of Bristol and Page (6) with algae, Duggar (10) with fungi, and Waksman (27) with the actinomycetes, all of which showed negative results, make one skeptical of nitrogen fixation by organisms other than the ones stated above. It was to confirm, and if confirmed, to extend the work of Löhnis, that the present work was undertaken.

EXPERIMENTAL

Soils from two locations near Minneapolis, one of them an unmanured experimental plat, were inoculated at different times throughout the year, into crystal violet lactose broth fermentation tubes and incubated for 48–96

TABLE 1

Fixation of nitrogen on Ashbey's agar

(Incubation 3 weeks)

CULTURE	SOURCE	N FIXED
		mgm.
Control	...	0
B. coli 1	Soil	0
B. cloacae 1	Soil	0
B. aerogenes 1	Soil	2.9
Soil infusion		3.4

TABLE 2

Fixation of nitrogen on Löhnis' agar

(Incubation 16 days)

CULTURE	SOURCE	N FIXED
		mgm.
Control	...	0
B. megatherium	Soil	0
B. cloacae 2	Soil	0
B. aerogenes 1	Soil	1.8

hours, at 25–37°. They were then streaked on triple dye agar (26) one tube to each plate, and sticky aerogenes-like colonies, one from each plate, were isolated. They were then inoculated back into lactose broth for the confirmatory test and re-streaked, and if necessary for purification, this was repeated a third or fourth time. They were then inoculated into peptone glucose media for the methyl red and Voges-Proskauer tests, and into gelatin tubes, which were incubated for several weeks at room temperature. Soil was also plated on Ashby's agar directly or after enrichment in Ashby's solution and in due time slimy colonies were picked. These were also subcultured into peptone glucose broth and gelatin. Many of these were found to be lactose fermenters after one or two transfers in lactose broth. That is, although the colonies were first isolated for *B. radiobacter*, lactose fermentation with evolu-

tion of gas could often be induced after they had been growing on lactose for a time. Undoubtedly many of the colonies often called *B. radiobacter* or *Rhizobium*, an unjustified use by Greig-Smith (16) of a generic name, itself of doubtful validity (22), have been of the aerogenes group. Similar organisms were isolated from impure cultures of *Azotobacter*. As Levine (18) and others have found, most of the soil organisms of this group were of the *Bacterium cloacae* (Jordan) L. & N. type, not true *B. aerogenes*. Gelatin liquefaction, however, was often delayed for several weeks. Long incubation of gelatin is imperative if liquefaction is to be used as a criterion in separating these species. Cultures of *B. radiobacter* were also obtained from other laboratories, and strains of *B. aerogenes* were isolated from water and flour. Gram-negative non-spore forming rods which did not liquefy gelatin or give a positive methyl red test, which produced gas and acid from glucose and lactose, and which gave a positive Voges-Proskauer test, were called *B. aerogenes*. Liquefying strains were diagnosed as *B. cloacae*. Cultures from those isolated were selected for

TABLE 3

Fixation of nitrogen on Löhnis' agar with glucose substitute for mannitol

(Incubation 16 days)

CULTURE	SOURCE	N FIXED
		mgm.
Control	...	0
B. megatherium	Soil	0
B. aerogenes 2	Soil	0
B. aerogenes 1	Soil	4.4

inoculation into media for analytical work. Generally those showing the most growth on Ashby's agar were chosen. They were first grown on Ashby's agar and a loup full of the culture transplanted into a tube of sterile water from which 1 cc. was inoculated into 1000 cc. Florence flasks or 800 cc. Kjeldahl flasks containing 135 cc. of Löhnis' or Ashby's medium[3] or a modification of

[3] The composition of Ashby's solution is as follows:

$MgSO_4 \cdot 7H_2O$	0.2 gm.
KH_2PO_4 made neutral to phenolthalein with NaOH	0.2 gm.
NaCl	0.2 gm.
$CaSO_4 \cdot 2H_2O$	0.1 gm.
Mannitol	15.0 gm.
Distilled H_2O	1000 cc.
$CaCO_3$	in excess

The composition of Löhnis' solution is as follows:

K_2HPO_4	0.5 gm.
Mannitol	10.0 gm.
Soil extract	100 cc.
H_2O	900 cc.

The soil extract was made by autoclaving 1000 gm. of soil with 1000 cc. of water for 30 minutes at 10 pounds pressure; 1.5 per cent agar agar was used to make the solid media.

one of these media as stated in table headings. In every case except where soil extract was used in the medium a trace of $Fe_2(SO_4)_3$ was added. The incubation time differed and will be indicated in each table heading. The flasks were incubated in a laboratory, the temperature of which varied considerably from week to week.

The ordinary Kjeldahl method to include nitrates, with salicylic acids and a reducing agent cannot be used for analysis of agar or other media containing free water. As shown by Bristol and Page (6) considerable nitrate is lost as HNO_3, and apparent fixation may be due to change of nitrate to protoplasmic

TABLE 4

Fixation of nitrogen on Löhnis' agar with lactose substituted for mannitol

(Incubation 3 weeks)

CULTURE	SOURCE	N FIXED
		mgm.
Control	...	0
B. coli 2	Soil	0
B. aerogenes 3	Soil	0
B. cloacae 3	Soil	0
B. coli 3	Soil	0
B. aerogenes 1	Soil	0.6
Soil	Soil	3.4

TABLE 5

Fixation of nitrogen on Ashbey's agar containing 100 cc. soil extract per liter

(20 days incubation)

CULTURE	SOURCE	N FIXED
		mgm.
Control	...	0
B. aerogenes 4	Soil	0
B. coli 4	Soil	0
B. coli 5	Soil	0
B. coli 6	Soil	0
Azotobacter chroococcum	Soil	9.1

nitrogen, which is not lost. The method used for media containing soil extract, in which nitrates were naturally present, was a modification of that used by Bristol and Page. To each flask 35 cc. of concentrated sulfuric acid was added and the agar was melted under a reflux condenser. After the agar was melted it was cooled, the moisture adhering to the condenser was washed into the flask, and 5 gm. of reduced iron was added. The reflux was again connected, the agar brought to a boil and boiled slowly for 30 minutes with an occasional washing of the condenser. Finally it was disconnected and the usual digestion and distillation were made, more acid, K_2SO_4, and $CuSO_4$ being added after frothing

had ceased. For media free from nitrates the ordinary Gunning-Kjeldahl method was used. The results are given as the milligrams of nitrogen fixed per 135 cc. of media. For titration 0.1 N or $\frac{1}{14}$ N acid and alkali were used. The results are given as averages of duplicates. The titrations checked within

TABLE 6

Fixation of nitrogen on Ashbey's agar

(14 days incubation)

CULTURE	SOURCE	N FIXED
		mgm.
Control	....	0
B. aerogenes 15	Stock culture labeled Friedländer's bacillus	0
B. aerogenes 10	Stock culture labeled Friedländer's bacillus	0
B. coli 7	Soil	
B. aerogenes 5		0
B. radiobacter	Vandecavaye, Pullman, Wash.	0
A. chroococcum		19.5

TABLE 7

Fixation of nitrogen in Ashbey's solution

(1 month incubation)

CULTURE	SOURCE	N FIXED
		mgm.
Control	....	0
B. aerogenes 13	Flour	0
B. aerogenes 1	Soil	1.5
B. coli 9	Soil	0
B. aerogenes 14	Flour	1.5
B. aerogenes 15	Stock culture labeled Friedländer's bacillus	0
B. aerogenes 10	Stock culture labeled Friedländer's bacillus	0
B. aerogenes 11	Milk	0
B. radiobacter 6	Richmond, Worcester, Ohio	0
B. aerogenes 15	Flour	0
B. coli 10	Soil	0

0.3 cc. (usually closer) of standard NaOH in all cases except where abundant fixation took place. Here, as would be expected in cultures, the differences were in some cases greater than in flasks in which no fixation, or only a little, took place. Differences of less than 0.5 cc. standard alkali between checks and inoculated flasks were ignored as being within possible experimental error.

All the *B. aerogenes*, *B. radiobacter*, and *B. radicicola* cultures grew very well on any of the media used and produced a copious slimy growth. Some of the cultures of *B. cloacae* but none of the *B. coli* grew well on the media. In liquid media the growth of *B. aerogenes* and *B. radiobacter* was much slower and less

TABLE 8

Fixation of nitrogen on Ashbey's agar

(16 days incubation)

CULTURE	SOURCE	N FIXED
		mgm.
Control	....	0
B. aerogenes	Soil	0
B. aerogenes	Soil	0
B. aerogenes 15	Stock culture labeled Friedländer's bacillus	0
B. aerogenes 10	Stock culture labeled Friedländer's bacillus	0
B. radicicola 2	Alfalfa	0
B. aerogenes 18	Water	0
B. aerogenes 19	Soil	0
B. aerogenes 20	Soil	0
B. aerogenes 21	Flour	0
B. aerogenes 11	Milk	0
B. radicicola 3	Alfalfa	0
B. aerogenes 22	Soil	0
B. aerogenes 23	Flour	3.7

TABLE 9

Fixation of nitrogen on Ashbey's agar containing 0.75 per cent glucose and 0.75 per cent mannitol

(Incubation 10 days)

CULTURE	SOURCE	N FIXED
		mgm.
Control	...	0
B. aerogenes 6	Soil	0
B. cloacae 4	Soil	0
B. aerogenes 7	Soil	0
B. coli 8	Soil	0
B. aerogenes 9	Soil	0
B. aerogenes 1	Soil	1.8
Azotobacter chroococcum	Soil	9.9

abundant. *B. coli* did not grow in the liquid media. However, in Koser's media without the uric acid and with CP. chemicals and water doubly distilled from $KMnO_4$ and H_2SO_4, a slight cloudiness resulted from many strains of *B. aerogenes*. This fact should be taken into account in interpreting Koser's (17) uric acid test.

That the *B. radicicola* strains did not fix nitrogen was a finding entirely unexpected by the author. Meanwhile, however, Barthel (2) has gone over the question of the ability of *B. radicicola* to fix nitrogen non-symbiotically and has obtained negative results. Against this work must be placed the careful work of Golding (15), Fred, Whiting, and Hastings (13), and others who obtained opposite results. At any rate it cannot now be stated positively that *B. radicicola* fixes nitrogen under all laboratory conditions. The results of the writer, like those of Barthel, would indicate that the organism does not fix nitrogen without the plant. The data here shown, however, are too few

TABLE 10

Fixation of nitrogen on Ashbey's agar containing 100 cc. soil extract per liter

(Incubation 2 weeks)

CULTURE	SOURCE	N FIXED
		mgm.
Control	....	0
B. aerogenes 10	Stock culture labeled Friedländer's bacillus	0
B. aerogenes 11	Milk	0
B. aerogenes 12	Soil	0
B. radiobacter 8	Richmond, Worcester, Ohio	0.8
B. radicicola 1	Alfalfa	0

TABLE 11

Fixation of nitrogen on Ashbey's agar

(Incubation 17 days)

CULTURE	SOURCE	N FIXED
		mgm.
B. aerogenes 23	Flour	3.6
B. radiobacter 7	Richmond, Worcester, Ohio	0
B. radiobacter 8	Richmond	2.4
B. radiobacter 6	Richmond	0

to permit the drawing of a definite conclusion. The results from the large number of strains of *B. aerogenes* show that there is a difference in their ability to fix free nitrogen. Some strains fixed nitrogen to a degree well beyond the limit of experimental error and this fixation was confirmed a number of times. Other strains, although they grew luxuriantly on a routine "nitrogen free" agar did so without fixing any nitrogen detected by the methods used. Either the not inconsiderable nitrogen found in agar even of "purified" brands, and in the atmosphere was sufficient, or else a fixation too small to detect, actually took place and further growth was inhibited by by-products, as has been

shown by Golding (15) and Giöbel (14) to be the case for *B. radicicola*. In the copious growth of these bacteria, actual cell substance is small in amount, so very little nitrogen is required to produce distinct growth, since the slime is known to be of a carbohydrate nature (7).

The cultures of *B. radiobacter*, although somewhat variable one from the other, are thought to be correctly diagnosed. Certainly they fit the microscopic and cultural descriptions of Beijerinck and Löhnis. Although several strains were isolated, only those obtained from other workers were used for analytical work. Conn's (9) carbol rose-bengal was found ideal for staining these slime-producing bacteria. Negative staining with nigrosin is also useful. There is a need for further research on *B. radiobacter*, which is always found in the isolation of *Azotobacter* and very often in the isolation of nodule bacteria. There is evidence to show that they as well as *B. aerogenes* stimulate nitrogen fixation, and the present work shows that although some strains of both appear not to fix nitrogen, others do fix nitrogen. Also there is a possibility that, under conditions whereby the by-products can be removed, fixation would proceed as shown for *B. radicicola* under laboratory conditions by Golding (15) and when growing in legume nodules by Giöbel (14).

The recent exhaustive work of Baldwin and Fred (1) on the fermentation of sugars by legume bacteria emphasizes the necessity for research on *B. radiobacter*. Although they state that this organism can be readily distinguished from all strains of the nodule bacteria by the large amount of acid produced from dextrine by *B. radiobacter*, they found that one of the four strains studied by them produced no acid from this carbohydrate. It would seem that these results did not justify the conclusion.

Finally it is evident that since some strains of *B. aerogenes* and some of *B. radiobacter* fixed nitrogen and that the colony appearance, slimy growth, staining reactions, cultural characters, and microscopic appearance were so similar, they are, as Löhnis has maintained for some years, closely related in any natural classification, as are also *B. radiobacter* and *B. radicicola*.

SUMMARY

1. Of 23 strains of *B. aerogenes* isolated from soil, flour, and water, 2, possibly 3, strains were found which fixed atmospheric nitrogen, when grown in routine nitrogen-free media.

2. Not all strains of *B. radiobacter* were found to fix nitrogen.

3. *B. aerogenes* or *B. radiobacter*, often both, were always encountered in the isolation of *Azotobacter*, and *B. radiobacter* was found nearly always in the isolation of the nodule bacteria.

4. *B. cloacae* was more often found in soil than *B. aerogenes*. No strains were found to fix nitrogen.

5. *B. radicicola* is very closely related phylogenetically to *B. radiobacter* and *B. aerogenes*. The placing of the genus *Rhizobium* by Bergey among the

autotrophic bacteria (family Nitrobacteriaceae) has no scientific justification. If maintained as a genus it belongs in or near the colon-typhoid group.

6. Need for further work on *B. radiobacter* is indicated.

REFERENCES

(1) Baldwin, I. L., and Fred, E. B. 1927 The fermentation characters of the root nodule bacteria of the Leguminosae. *Soil Sci.* 24: 217-230.

(2) Barthel, Chr. 1926 Kunna baljväxtbakterier i renkultur fixera atmosfäriskt kväve? Meddel. 308 Centralanst. Försöksv. Jordbruksområdet., Bakt. Avd. no. 43.

(3) Beijerinck, M. W., and van Delden, A. 1902 Ueber die Assimilation des freien Stickstoffs durch Bakterien. *Centbl. Bakt.* (II) 9: 3-43.

(4) Bergey, D. H., and Committee of the Society of American Bacteriologists 1921 Manual of Determinative Bacteriology. Baltimore, Md.

(5) Bertholet, M. 1894 Nouvelles recherches sur les microorganismes du sol fixateurs de l'azote. Bul. Soc. Chim. France. (Ser. 3) 11: 784-793.

(6) Bristol, M., and Page, H. J. 1923 A critical inquiry into the alleged fixation of nitrogen by green algae. *Ann. Appl. Biol.* 10: 378-408.

(7) Buchanan, R. E. 1909 The gum produced by *Bacillus radicicola*. *Centbl. Bakt.* (II) 22: 371-396.

(8) Buchanan, R. E. 1925 General Systematic Bacteriology. Baltimore, Md.

(9) Conn, H. J. 1921 Rose bengal as a general bacterial stain. *Jour. Bact.* 6: 253-254

(10) Duggar, B. M. 1916 Studies in the physiology of the fungi: I. Nitrogen fixation. *Ann. Mo. Bot. Gard.* 3: 413-437.

(11) Fischer, H. 1916 Über qualitative und quantitative Leistungen stickstoffsammelnder Bakterien im Wasser und im Boden under Wasserbedeckung. *Centbl. Bakt.* (II) 46: 304-320.

(12) Fischer, H. 1918 Das Problem der Stickstoffbindung (Festlegung) des Luftstickstoffs bei niederen Pflanzen. *Ber. Deut. Bot. Gesell.* 35: 423-454.

(13) Fred, E. B., Whiting, A. L., and Hastings, E. G. 1926 Root nodule bacteria of Leguminosae, Wis. Agr. Exp. Sta. Bul. 72.

(14) Glöbel, G. 1926 The relation of the soil nitrogen to nodule development and fixation of nitrogen. N. J. Agr. Exp. Sta. Bul. 436.

(15) Golding, J. 1905 The importance of the removal of products of growth in the assimilation of nitrogen by the organisms of the root nodules of leguminous plants. *Jour. Agr. Sci.* 1: 59-64.

(16) Grieg-Smith, R. 1912 The determination of Rhizobia in the soil. *Centbl. Bakt.* (II) 34: 227-229.

(17) Koser, S. A. 1918 The émployment of uric acid synthetic medium for the differentiation of *B. coli* and *B. aerogenes*. *Jour. Infect. Diseases* 23: 377-379.

(18) Levine, M. 1921 Bacteria fermenting lactose and their significance in water analysis. Iowa State Col. Eng. Exp. Sta. Bul. 62.

(19) Lipman, J. G. 1903 Experiments on the transformation and fixation of nitrogen by bacteria. N. J. Agr. Exp. Sta. Ann. Rpt. 1903: 217-285.

(20) Lipman, J. G. 1905 Azotobacter studies. N. J. Agr. Exp. Sta. Ann. Rpt. 1905: 254-280.

(21) Löhnis, F. 1905 Beiträge zur Kenntnis der Stickstoffbakterien. *Centbl. Bakt.* (II) 14: 582-604.

(22) Löhnis, F., and Hansen, R. 1921 Nodule bacteria of leguminous plants. *Jour. Agr. Res.* 20: 543-556.

(23) Löhnis, F., and Pillai, N. K. 1907-1908. Ueber stickstoffixierende Bakterien. *Centbl. Bakt.* (II) 19: 87-96; 20: 781-799.

(24) PILLAI, N. K. 1908 Untersuchung über den Einfluss der Düngung und anderer Faktoren auf die Tätigkeit der Microorganismen des Bodens. Dissertation, Buch-und Steindruckerei, Emil Stephen. Leipsig.

(25) RICHARDS, E. H. 1917 The fixation of nitrogen in faeces. *Jour. Agr. Sci.* 8: 299–311.

(26) SKINNER, C. E., AND MURRAY, T. J. 1924 Medium for the inhibition of spreaders and the isolation of *B. coli* and *B. aerogenes*. *Jour. Infect. Diseases* 34: 585–591.

(27) WAKSMAN, S. A. 1920 Studies in the metabolism of the actinomycetes: III. Nitrogen metabolism. *Jour. Bact.* 5: 1–30.

(28) WELDIN, J. C. 1927 The colon-typhoid group of bacteria and related forms. Relationships and classification. *Iowa State Col. Jour. Sci.* 1: 121–197.

(29) WINOGRADSKY, S. 1893 Sur l'assimilation de l'azote gazeux de l'atmosphere par les microbes. *Compt. Rend. Acad. Sci.,* 116: 1385–1388.

THE VOLUME WEIGHT OF SOILS AS A PHYSICAL CHARACTERISTIC OF THE SOIL PROFILE[1]

A. F. LEBEDEV

University of Rostov on Don, U. S. S. R.

Received for publication December 1, 1926

The weight of a unit volume of soil with an undisturbed structure dried at 105–110° is the volume weight of the soil. The method for this determination is given in all the texts on soils. The volume weight of the soil in its horizons gives a general picture of the consolidated make-up of the soil particles, the compactness of the soil, and the amount of chemical substances in a unit volume of soil. Notwithstanding the obvious importances of the volume weight data for the physical characteristics of the soils, soils men and agronomists rarely utilize this physical constant either in describing the soil profile or in studying the dynamics of soil processes. The author suggests the determination of the volume weight of the various horizons of the soil profile as a very useful characteristic because of the following considerations:

1. The change in the volume weight of the various horizons of the soil profile is in itself a supplementary physical characteristic of the soil (for the soil type and its variables), as is shown in table 1. In this table the weight of the various horizons of the soil of 500 cc. volume in successive layers of 5 cm. depths is given. Both soils represent the south Russian chernozem; one comes from Odessa (the northwestern shore of the Black Sea), the other soil comes from Rostov on Don (where the Don enters the Azov Sea). Table 2 gives the volume weight of the soil for each 50-cm. interval.

The volume weight of each soil at a depth of 150–200 cm. is taken as 100 per cent. The data of the volume weight for other depths are referred to this.

The change in volume weight in the various horizons in the Odessa and Rostov profiles definitely points to the differences in these two soils. In the Odessa chernozem there is a compact horizon at a depth of 50–150 cm. whereas in the Rostov chernozem gradual compactness of the soil is observed with the depth.

2. The determination of the volume weight of soils makes it possible to judge how the various substances in the soil are translocated from one horizon into the other during the entire period of development of the particular soil. A chemical analysis which gives only the percentage relationships of the various constituents of the soil is insufficient for an accurate characterization of the translocation of the substances in the soil profile. Exact data may be obtained

[1] Translated from the Russian by J. S. Joffe, New Jersey Agricultural Experiment Station.

only when the percentage content of the substance studied is multiplied by the volume weight of this horizon.

TABLE 1

The weight of 500 cc. of soil

DEPTH OF SOIL	ODESSA	ROSTOV ON DON
cm.	*gm.*	*gm.*
0–5	647.6	623.1
5–10	641.0	660.8
10–15	584.7	662.2
15–20	539.1	663.3
20–25	530.3	652.8
25–30	513.2	642.1
30–35	536.7	662.4
35–40	514.6	682.6
40–45	485.4	692.7
45–50	578.1	702.6
50–55	640.4	708.8
55–60	650.1	715.1
60–65	674.4	724.8
65–70	718.4	734.5
70–75	741.0	718.2
75–80	763.6	690.6
80–85	714.2	712.2
85–90	756.6	733.6
90–95	695.5	716.5
95–100	709.2	699.2
100–105	742.5	716.3
105–110	727.9	733.4
110–115	713.2	752.3
115–120	703.5	771.1
120–125	721.4	773.9
125–130	710.2	776.4
130–135	725.4	779.7
135–140	751.4	780.0
140–145	704.7	758.1
145–150	694.3	733.0
150–155	633.4	746.3
155–160	628.0	759.3
160–165	643.0	762.6
165–170	623.7	765.7
170–175	613.1	765.7
175–180	637.4	782.3
180–185	600.0	799.0
185–190	606.6	799.0
190–195	638.8	806.0
195–200	649.9	813.0

3. A determination of the volume weight in the profile permits an accurate study of the dynamics of the various processes taking place in the soil. Be-

cause of seasonal variations, it is impossible without an accurate knowledge of the volume weight of the various horizons in the soil profile to trace and to follow the content of one or another substance in the horizons as well as the total balance of these substances in the soil. What has been said is especially important in conection with the study of the water régime of soils.

4. The determination of the volume weight of the soil profile together with the chemical analysis gives an accurate figure of the nutrient resources in the separate horizons as well as throughout the profile. The percentage composition of the soil does not permit such a calculation.

5. On the basis of consideration 4 one may compare the nutrient resources in the various soils. For instance, if it is assumed that according to chemical analysis the Odessa chernozem contains 0.11 per cent P_2O_5 and the Rostov chernozem 0.10 per cent P_2O_5, then the Odessa chernozem is 10 per cent richer in P_2O_5 than the Rostov chernozem. However, if we take into consideration

TABLE 2

Volume weight of soils at 50-cm. depth intervals

DEPTH	ODESSA		ROSTOV	
cm.	*gm.*	*per cent*	*gm.*	*per cent*
0–50	5570 7	89	6646 6	85
50–100	7063 4	112	7153 5	92
100–150	7194 5	115	7574 2	97
150–200	6273 9	100	7798 9	100
0–200	26102 5		29171 2	

the volume weight of these soils and calculate the content of P_2O_5 over a square meter to a depth of 50 cm. (see table 2) the following will be obtained:

P_2O_5 in the Odessa chernozem = 6.127 gm. (0.11 per cent × 5570)
P_2O_5 in the Rostov chernozem = 6.647 gm. (0.10 per cent × 6647)

We see that the Rostov soil, notwithstanding its lower percentage content of P_2O_5, has a total of 8.5 per cent more than the Odessa soil. This is because the mass of the Rostov soil in the horizon of 0–50 cm. is 19.3 per cent greater than the mass of the corresponding horizon in the Odessa soil.

It is also clear that if we apply to the Odessa and the Rostov soils the same amount of any one fertilizer, its concentration in these soils will vary. The significance of consideration 5 for experimental fields is self-evident.

6. The general data on mechanical analysis of soils give a more complete characterization of the soil profile when they are referred to the volume weight of the corresponding horizon. This is especially important in connection with a clay fraction, the amount of which determines the inner surface of the soil. If the mechanical analysis of the soils shows that the Odessa chernozem contains just as much clay as the Rostov chernozem then taking into considera-

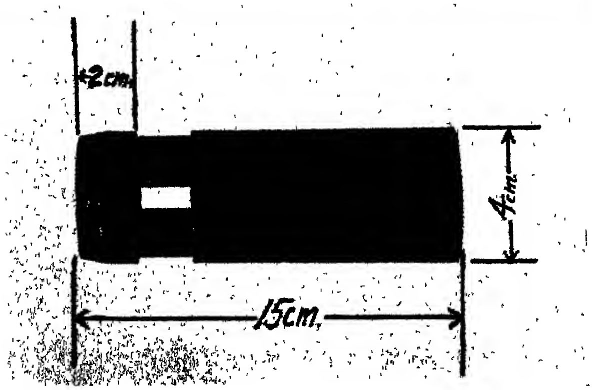


FIG. 1

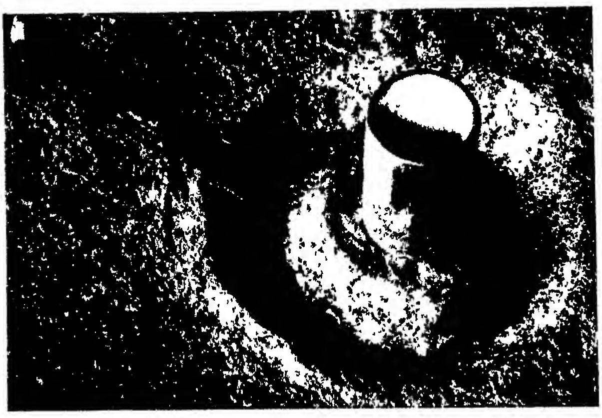


FIG. 2

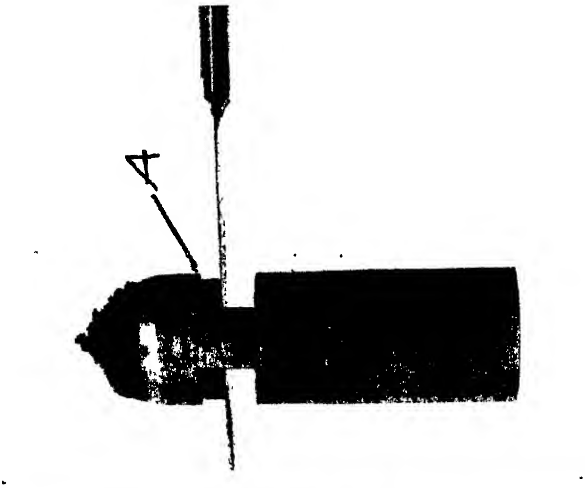


FIG. 3

tion the volume weight of these soils to a depth of 50 cm. one must conclude that the surface energy in the Rostov soil (see table 2) is 19.3 per cent greater than in the Odessa soil. Such a characteristic may be of considerable interest in connection with a series of problems (movement of water, processes of formation of horizons, leaching processes, etc.).

DETERMINING THE VOLUME WEIGHT OF THE SOILS

The following method of determining the volume weight of soils is used by the author. The sharp end of a thin-wall steel tube (pl. 1, fig. 1) is inserted without turning into the wall of the soil cut at a depth of 2.5 cm. (pl. 1, fig. 2). The soil from the outer side of the tube is cut off at an angle with a knife so that there should remain a heaping surplus above the cutting edge of the tube (pl. 1, fig. 3). After that the tube is separated from the soil. This surplus is carefully cut off with a sharp knife until the surface is even with the cutting edge of the tube. The surplus of the soil at the inner edge of the tube is cut off with a knife through the two openings in the tube (*A*, pl. 1, fig. 3). When the soil is cut off at the top and the bottom we have a cylinder of undisturbed structure. After the dry weight of this cylinder of the soil has been determined and its volume is known, the volume weight is obtained. For more careful investigations it is best to make two or more parallel determinations of the volume weight in order to eliminate individual variations.

THE ABSORPTION OF RAIN WATER DURING VEGETATION BY THE SOIL AND ITS UTILIZATION BY PLANTS

N. TULAIKOV AND A. KOZHEVNIKOV[1]

Saratov Regional Experiment Stations

Received for publication April 15, 1926

Practical farmers have long known from experience that in dry regions moisture is the fundamental factor that determines the yield of crops. This also has been shown experimentally by the various experiment stations in the dry regions.

THE PROBLEM INVESTIGATED

The moisture problem under investigation at the Saratov Experiment Stations consists in studying the course of water utilization by the plants under field conditions during the vegetation period. A study was also made on the utilization by the soil of the moisture from the fall rains and spring thawing of snow under various conditions of relief and tillage. Detailed observations have been made since 1924.

METHODS OF INVESTIGATION

In the early spring after the snow had melted, plots were laid out in fields of winter rye, spring wheat, and sunflower. The soils in all the plots were as uniform as possible under the conditions. The plots of the winter rye of the early fallow, and of the spring wheat were in the second crop of the rotation. The sunflower plot was in the sixth crop of the rotation.

They second rotation plot was a dark chestnut sandy loam with a clay subsoil. The soil was light and permeable to water in the surface horizons; the so-called "dead moisture" in the soil was 8 per cent of the weight of the absolutely dry soil.

The soil under the sunflower in the sixth rotation was similar to the soil in the second rotation, except that within this field were alkali spots, from which it was impossible to avoid taking samples for moisture determinations.

Moisture determinations were made on 5-cm. layers to a depth of 50 cm. From the winter rye plot, samples were taken from the time the rye began to grow in the spring; and from the other plots, beginning the day of sowing the corresponding seeds. Sampling was done with a boring cube of the Izmail'skii construction.

[1] Translated from the Russian by Dr. J. S. Joffe, New Jersey Agricultural Experiment Station.

TABLE 1

Metereological conditions during the vegetation period in 1926

Day in the month	April			May			June			July			August		
	Relative humidity of the air	Average daily temperature	Rainfall	Relative humidity of the air	Average daily temperature	Rainfall	Relative humidity of the air	Average daily temperature	Rainfall	Relative humidity of the air	Average daily temperature	Rainfall	Relative humidity of the air	Average daily temperature	Rainfall
		°C.	mm.		°C.	mm.		°C.	mm.		°C.	mm.		°C.	mm.
1	..	....	...	46	14.4	....	44	12.7	....	65	17.5	....	51	22.6	0.3
2	..	....	...	42	15.9	....	41	16.4	....	67	16.1	....	66	20.8	0.2
3	..	....	...	41	16.3	....	36	20.4	....	63	18.0	....	70	18.1	1.1
4	..	....	...	44	17.1	....	36	22.7	....	57	16.7	....	60	20.3	1.0
5	..	....	...	64	13.1	....	52	23.2	....	51	20.7	0.4	85	18.5	2.7
6	..	....	...	88	1.6	15.2	41	25.6	2.3	60	15.9	....	66	16.9	....
7	..	....	...	98	3.6	25.9	56	23.3	9.2	64	13.4	....	61	14.2	0.0
8	..	....	...	96	5.5	1.7	79	18.6	1.0	42	17.7	....	73	18.7	0.6
9	..	....	...	75	5.3	10.0	68	20.8	1.4	57	16.9	....	59	15.6	1.5
10	..	....	...	89	8.0	....	70	19.8	1.8	47	14.1	....	63	13.4	....
11	..	....	...	74	10.8	....	90	10.7	0.1	51	16.5	....	64	14.3	....
12	..	....	...	58	11.6	3.1	78	9.3	....	45	19.5	....	63	13.2	....
13	..	....	...	99	9.6	30.5	56	13.1	6.4	58	21.4	....	65	18.5	....
14	..	....	...	81	9.8	0.7	96	13.5	11.4	56	22.5	....	53	17.5	....
15	..	....	....	..	10.4	....	86	14.5	5.5	62	21.0	....	72	15.8	12.3
16	..	....	...	..	13.4	....	68	16.3	....	52	27.9	....	91	18.5	5.5
17	99	0.6	...	47	16.5	....	65	19.7	....	66	23.6	....	72	17.3	7.1
18	65	6.9	...	57	18.2	....	73	16.9	0.3	85	15.6	11.7	89	15.3	5.1
19	66	8.3	...	42	19.0	...	62	16.3	....	63	12.8	....	82	16.8	6.8
20	69	10.9	...	61	15.8	....	59	20.2	....	45	15.3	....	69	16.6	....
21	71	12.2	...	40	16.8	....	57	21.4	....	47	22.8	....	94	13.9	13.1
22	68	14.6	...	..	10.9	....	69	16.7	1.5	31	26.5	....	91	14.3	1.5
23	42	18.7	...	39	16.5	....	54	19.3	....	40	26.5	....	89	15.3	0.4
24	47	18.6	...	39	20.1	....	58	21.3	....	50	24.7	....	74	16.3	0.9
25	68	15.3	....	38	21.4	....	61	21.1	2.5	79	19.3	....	76	15.6	2.4
26	72	5.8	...	39	19.7	....	68	20.9	....	63	19.9	....	69	15.4	....
27	70	6.0	...	44	21.2	....	74	19.8	5.2	61	21.5	....	56	19.2	2.3
28	69	4.9	...	..	21.7	....	78	19.6	7.0	51	19.2	....	76	14.9	2.7
29	59	9.3	....	..	21.4	....	84	19.1	6.7	44	21.1	....	67	14.8	1.1
30	48	12.3	....	40	22.7	....	74	21.7	0.2	35	25.9	....	73	14.6	....
31	..	....	...	39	13.8	....	..	....	....	41	24.3	....	78	12.0	5.6
					14.3	87.1		18.5	62.5		19.8	21.0		16.5	84.0
		6.7			14.4	38.1		19.9	39.1		21.3	58.1		19.1	36.3

Although the method of determining soil moisture is crude and does not exclude the possibility of obtaining data of considerable variations in percentage of moisture, the errors were unavoidable because of the variations in the surface soil and the subsoil of the fields. At times the variations between

two borings made close to each other were greater than 2 per cent. The fluctuations in the distribution of moisture in the various layers at times were even greater. It would have been possible to eliminate some of these errors by taking several parallel borings, but under the conditions of the experiment where a large number of samplings were to be made this was impracticable. It is well to remember that in this investigation the authors were interested not so much in the absolute resources of the soil moisture, as in the changes occurring during a certain period when they are more easily followed if more frequent determinations are made.

Simultaneously with this part of the work, a study was made on the amount of moisture used by cultivated plants. For this purpose the soil moisture was determined on the different layers to a depth of 100 cm. every 5 or 10 days. Samples of plants were also taken for the determination of the increase of dry matter during the process of growth. The data of this study were partly utilized.

METEOROLOGICAL CONDITIONS DURING THE INVESTIGATION

Table 1 gives the weather conditions during the period of vegetation in 1926 as supplied by the meterological division of the Saratov Experiment Station. The period of vegetation in 1926 may be characterized first of all by a lower temperature than the average normal. While in May the temperature was close to the average it was 2°C. lower than the normal during June, July, and August.

The distribution of moisture also was unusual for the Saratov conditions. During May the rainfall was greater than normal. Because of this the field work was delayed. There was also more than the normal rainfall during June but the rains came at frequent intervals (it rained 17 out of 30 days). During July the rainfall, which is usually very regular, was less than normal. During August again there were frequent small rains (21 out of 31 days). The total rainfall during this month was twice the normal.

ANALYSIS OF THE MATERIAL OF THE INVESTIGATION

The course of the changes in the moisture content of the soil with various plants and fallow is given in tables 2–9. Tables 2, 4, 6, and 8 give the data of the moisture content of the soil in percentage of the absolute dry weight of the soil. Beside the data on the moisture content in the various layers to a depth of 50 cm., calculations were made on the moisture content in the soil from 0–20 cm. and from 20–50 cm. These determinations were made because it has been established in former years that under the conditions of the Saratov Experiment Stations the rains do not penetrate the soil more than 20 cm.

Tables 3, 5, 7, and 9 give the moisture content of the layers of soil at 10-cm. intervals; the soil moisture values obtained were expressed in per cent relative to the original resources of the soil moisture, in order to be able to follow

TABLE 2

Moisture content of soil under winter rye, in per cent

DEPTH	APRIL		MAY									JUNE												JULY				
	22	26	10	12	17	19	21	24	26	28	31	2	4	7	9	11	15	17	22	24	26	28	30	2	5	7	9	12
cm.																												
0–5	27.2	22.5	26.7	26.7	27.1	24.4	18.1	17.7	15.7	16.5	11.3	12.1	12.9	8.3	18.1	15.3	20.9	17.3	13 2	12 0	9 5	14 1	21.8	19.5	12.5	13.3	10.0	10.7
5–10	....	....	24.1	26.7	28.0	24 5	19.0	16 8	18.8	16.0	13.3	12.5	12.6	6.8	14.4	13.1	18.5	17.9	20 4	11.0	13 8	10.8	12.6	16 0	12.5	13.3	13.0	11.9
10–15	26.2	25.2	25.2	36.9	29.0	25.7	19.1	17.3	15.8	16.8	14.2	9.4	17.1	11.1	11.3	13.1	11.6	21.1	13 1	11.9	11 0	10.6	11.5	15.5	11.5	13.4	13.7	10.9
15–20	....	....	21.3	27.0	26.5	26.8	19.3	20.5	16.1	17.1	15.2	15.1	15.1	12.1	15.0	16.6	11.6	12.1	14 6	8 6	11 3	10.9	11.5	12.9	11 1	15.0	14.2	11.3
20–25	22 0	22.3	22.0	22.1	24.2	22.5	20.1	21.4	17.7	17 3	16.8	15.1	14.4	12 9	13.5	16.8	11.3	12.8	13 7	9 0	12 2	10.2	12.1	14 4	13.2	15.3	15.9	12.4
25–30	....	....	21.1	22.3	25.2	23.4	20.6	21.4	19.3	17.6	17.3	10 6	14.7	9.3	14.3	16.5	11.7	13.7	12.2	13.6	12.4	9.9	10.5	14.9	13.5	14.7	15.2	12.9
30–35	19–8	21.9	19.6	22.2	25.5	23.1	20.6	19.7	20.6	18.0	17.5	12.1	13.8	13.2	15.2	16.1	12.5	14.1	13.2	13 9	12 4	11.6	10 5	14.1	14.1	13.5	14.5	12.5
35–40	....	....	17.2	20.5	23.0	19.0	19.2	19.4	19.8	17.3	15.1	10.9	13.0	13.1	14.6	14.8	12.3	14.4	12 2	10.9	10.7	9.8	8.0	13.4	13.2	11.1	13.0	11.4
40–45	21.0	20 3	14.2	18.3	20.5	19.4	17.7	17.3	17.9	14.9	14.8	11.6	12.0	13.6	12.3	15.2	13.4	12.6	10.1	10.7	9.5	10.8	8 6	11.5	11.4	11.7	9.2	8.6
45–50			14.4	16.8	18.6	18.1	16.4	16.7	16.0	13.0	13.8	11.6	10.5	9.8	9.9	12.8	11.3	11.0	9.2	8.8	8 9	9.1	7.3	9.6	10.7	8.1	8.5	8.6
Average																												
0–20	26.7	23.8	24.3	26.1	22.5	22 3	18.9	18.2	16.6	16.6	13.5	12.3	14.4	9.6	14.7	14.8	15 6	17.7	15.3	10.9	11.4	11.6	14.3	16.0	11.9	13.7	12.7	11.2
20–50	20.9	21.5	18.1	20.4	22.8	20.9	19.1	19.3	18.5	16.4	15.9	12.0	12 6	12.0	13.3	15.4	13.8	13.1	11.8	11.1	11.1	10.6	9.5	13.0	12 7	12.4	12.7	11.1
0–50	23.2	22.4	20.6	23.9	24.7	22.7	19.0	18.1	17.7	16.4	14.9	12 1	13.6	11.0	13.9	14.9	14.8	14.7	13.2	11.0	11.2	10.8	11.4	14–2	12.4	12.9	12.7	11.1

TABLE 3

Changes in moisture content of soil under winter rye in relation to its original moisture resources

DEPTH	APRIL		MAY									JUNE												JULY				
	22	26	10	12	17	19	21	24	26	28	31	2	4	7	9	11	15	17	22	24	26	28	30	2	5	7	9	12
cm.																												
0–10	100	83	94	98	101	90	68	64	63	60	45	45	47	27	60	52	72	71	62	42	41	46	63	65	46	19	42	42
10–20	100	96	88	94	106	100	73	74	61	64	56	45	61	44	50	56	44	43	53	39	42	41	44	54	43	54	53	42
20–30	100	101	98	101	112	104	92	97	84	79	58	66	50	63	75	75	75	73	58	49	56	46	51	69	60	69	70	57
30–40	100	116	93	107	127	106	100	98	102	89	82	68	67	67	75	78	73	71	64	63	58	54	46	74	68	62	74	70
40–50	100	97	96	83	93	89	81	81	85	66	68	55	53	56	52	67	58	56	56	46	44	47	38	50	52	47	42	41

TABLE 4

Moisture content of soil under spring wheat, in per cent

DEPTH	MAY									JUNE											JULY										
	10	12	17	19	21	24	26	28	31	2	4	9	11	15	17	22	24	26	28	30	2	5	7	9	12	14	16	19	21	23	26
cm.																															
0–5	32.0	27.9	33.0	32.6	28.1	25.7	24.6	26.6	20.6	19.7	20.2	21.8	18.4	24.3	23.8	16.2	15.6	11.7	11.1	10.2	20.3	15.2	15.2	12.0	10.7	10.0	12.4	13.5	13.8	10.3	9.5
5–10	32.5	30 9	32.8	33.3	31.0	27.0	23.7	23.5	22.4	18.3	18.6	16.4	21.0	24.3	22.0	18.4	12.9	11.6	11.1	10.7	15.1	13.8	14.7	14.2	11.2	10.7	13.6	10.0	12.0	10.7	11.4
10–15	31.2	31.4	33.3	30.9	26.6	29.4	24.1	25.7	22.4	18.2	18.7	15.5	17.5	16.0	22.0	14.9	14.5	11.7	10.0	16.1	14.4	22.1	16.2	18.4	11.0	12.9	14.7	10.2	11.4	10.9	11.5
15–20	22.5	32.5	28.3	26.6	24.2	27.4	20.6	22 0	19.5	19.1	18.9	14.4	17.5	15.2	19.0	15.9	14.7	11.8	10.5	14.7	14 0	14.6	16.6	18.0	11.9	13.7	14.9	11.0	12.0	11.5	13.0
20–25	31.1	22.9	27.6	23.0	22.0	23.8	20.7	21.1	18.3	17.1	19.3	14.4	18.1	21.4	15.9	16.6	14.7	13.2	10.8	15.4	14.2	14.2	15.8	14.8	13.0	14.4	15.6	11.7	14.6	11.7	13.1
25–30	22.6	22.8	26.7	23.7	20.5	23.0	19.6	20 9	17.9	17.9	20.4	16 1	17.5	13.7	15.7	17.2	16.1	14.7	10.9	15.0	14 4	14.2	15.2	19.2	14.2	14.7	15.3	15.4	14.7	10.0	13.3
30–35	22.9	23.3	25.7	24.6	21.8	22.6	19.7	20 4	18.7	19.5	19.1	18.3	17.3	15.7	16.2	18.1	14.5	14.4	10.4	14.4	13.7	16.7	13.4	18.3	11.7	14.7	16.0	12.9	14.0	10.9	11.3
35–40	21.7	22.1	23.8	22.1	19.4	27.6	27.8	21.3	18.7	18.4	18.4	17.7	17.7	15.2	16.3	14.3	15.1	13.5	11.0	13.8	14.3	15.7	13.1	18.0	12.1	13.8	16.4	12.2	12.8	10.0	12.2
40–45	19.6	20.7	21.0	20.2	19.0	20.4	19.2	20.1	18.2	16.7	17.4	16.7	16.9	15 3	16.6	11.9	13.4	12.3	10.2	11.5	12.7	14.0	13.6	17.2	11.0	12.8	14.2	11.7	11.9	8.7	10.7
45–50	19.0	18.6	27.4	20.6	17.7	18.9	18.6	18.8	19 6	16.3	18.2	15.8	16.9	14.9	15.6	11.0	14.2	11.4	6.9	13.6	12.6	13.0	10.1	16.4	9.9	13.2	14.1	13.1	11.1	9.2	10.0
Average																															
0–20	31.3	30.7	31.8	30.8	27.5	27 6	23.2	24.4	21.2	18.8	19.1	17.0	18.6	19.9	21.7	16.3	14.4	11.7	10.7	12.5	15.9	16.5	15.7	15 6	11.2	11.8	13.9	11.2	12.3	10.8	11.3
20–50	22.8	21.7	25.4	22.4	20.1	22.7	20.9	20.4	18.8	17.6	18.8	16.5	17.4	17.3	16.1	14.4	14.7	13.3	10.0	13.9	16.0	14.6	13.5	17.3	15.3	13.9	15.3	12.8	13.2	10.1	11.8
0–50	26-2	25.3	28.0	25.8	23.0	24.6	21.9	22.0	19.6	18.1	18.9	16.7	17.9	17.6	18.7	15.2	14.6	12.6	10.3	13.5	16.0	15.4	14.4	16.6	11.7	13 1	14.7	12.2	12.8	10.4	11.6

TABLE 5

Changes in moisture content of soil under spring wheat in relation to its original moisture resources

DEPTH	MAY									JUNE											JULY										
	10	12	17	19	21	24	26	28	31	2	4	9	11	15	17	22	24	26	28	30	2	5	7	9	12	14	16	19	21	23	26
cm.																															
0–10	100	88	100	100	92	82	75	78	67	69	60	59	61	75	71	54	47	36	34	32	55	46	46	44	34	32	44	36	40	32	32
10–20	100	105	102	95	84	95	73	78	69	61	62	49	58	52	68	51	49	39	34	51	47	60	54	60	38	44	49	35	39	37	40
20–30	100	100	100	92	86	95	77	80	70	67	71	54	66	68	64	63	57	53	53	58	67	53	58	67	51	54	57	50	54	40	49
30–40	100	100	110	100	92	110	101	93	84	85	84	81	78	69	73	66	66	62	48	63	63	73	60	81	53	64	73	56	60	47	52
40–50	100	100	125	106	95	100	98	100	98	85	92	85	87	78	87	59	72	62	44	65	65	70	61	87	54	67	73	65	61	46	51

TABLE 6

Moisture content of soil under sunflower, in per cent

DEPTH	MAY								JUNE										
	12	17	19	21	21	26	28	31	2	4	7	9	11	15	17	22	24	26	30
cm.																			
0–5	29.2	31.4	25.0	22.5	25.5	22.8	30.4	21.4	19.2	18.3	....	22.7	21.4	22.7	25.1	18.3	21.0	18.7	25.6
5–10	28.5	31.9	29.0	26.7	25.9	24.6	30.3	23.2	21.2	23.0	18.8	23.2	20.4	21.6	26.4	20.9	22.9	19.9	19.2
10–15	30.8	32.1	28.9	28.8	27.5	30.1	26.7	21.9	20.1	20.5	20.5	21.4	21.0	18.2	26.2	18.3	21.0	23.1	17.6
15–20	29.3	31.7	29.2	25.4	31.1	31.6	23.7	22.8	21.8	25.5	20.6	23.6	18.9	18.9	25.2	23.0	21.5	22.5	15.8
20–25	31.7	26.7	31.4	22.8	32.3	29.1	24.2	26.7	23.0	25.5	20.3	22.3	18.2	18.4	23.9	25.4	21.6	20.6	15.3
25–30	31.0	30.4	31.0	29.5	26.9	26.0	22.0	25.5	22.0	25.8	17.9	23.1	18.6	18.1	23.2	24.5	22.1	19.6	16.0
30–35	29.2	32.4	30.4	30.2	26.4	25.4	23.6	23.6	22.9	24.3	18.8	23.0	23.9	20.3	23.3	24.3	23.9	20.7	16.8
35–40	29.7	29.3	29.5	26.2	27.1	21.6	27.9	21.5	20.1	24.0	24.6	23.4	29.7	26.1	21.1	24.8	23.7	20.5	13.7
40–45	26.2	28.1	28.1	24.8	23.9	26.7	29.9	22.2	20.1	22.1	26.3	23.8	31.3	30.3	22.7	21.6	23.6	20.7	19.0
45–50	25.6	26.8	26.9	24.4	26.4	26.6	26.4	21.2	19.6	24.4	24.8	21.4	30.9	31.7	24.4	22.9	26.9	21.6	19.0
Average																			
0–20	29.4	31.8	28.0	25.8	27.5	27.3	27.8	22.3	20.6	21.8	21.3	22.7	20.6	20.1	25.7	20.1	21.6	21.0	19.5
20–50	28.9	28.9	29.5	26.2	27.2	26.4	25.7	23.5	21.3	24.4	22.1	21.2	25.4	24.1	23.1	23.9	23.6	20.6	15.0
0–50	29.1	30.1	28.9	26.1	27.3	26.7	26.5	23.9	21.0	23.3	21.8	21.8	23.5	22.5	24.1	22.4	22.8	20.8	16.8

DEPTH	JULY													AUGUST								
	2	5	7	9	12	14	17	19	21	23	26	28	30	2	7	9	13	16	18	20	25	31
cm.																						
0–5	23.5	19.7	17.9	11.8	16.2	11.2	15.3	15.3	13.8	14.2	12.7	13.8	11.9	11.3	15.3	10.9	19.1	24.3	17.6	25.0	20.5	27.6
5–10	21.0	19.3	16.7	16.3	16.5	14.7	14.8	12.5	14.1	13.2	12.5	14.3	13.9	16.0	18.3	12.7	18.9	15.0	17.1	23.4	19.6	25.9
10–15	24.0	18.0	21.1	18.0	17.1	19.3	23.2	12.0	14.3	13.6	14.1	14.5	13.3	14.2	19.2	13.5	16.5	16.6	14.2	20.9	24.1	16.4
15–20	25.8	24.3	25.5	21.7	16.1	18.6	23.1	12.5	13.7	15.4	17.4	18.2	16.7	21.0	19.5	12.9	17.0	20.9	17.1	19.9	22.2	21.0
20–25	24.3	25.8	28.5	26.1	19.0	16.5	22.2	14.9	15.2	15.3	19.8	13.6	16.6	22.6	23.5	14.8	18.0	19.9	24.2	23.6	17.0	18.5
25–30	24.8	23.5	25.5	20.9	21.7	18.3	21.8	16.3	15.4	14.7	18.8	14.7	18.1	19.7	19.7	16.6	18.1	16.0	23.1	20.2	13.9	21.3
30–35	24.3	24.8	22.3	21.6	18.9	17.4	20.6	14.6	16.6	12.4	17.6	16.7	15.0	20.0	17.0	15.6	18.3	15.6	23.3	15.9	13.1	19.7
35–40	23.4	22.2	21.5	23.8	18.1	15.8	17.3	13.7	15.6	12.4	15.4	16.8	13.9	18.1	16.2	14.7	20.8	14.8	19.9	24.7	12.9	11.0
40–45	23.5	20.1	20.2	19.6	18.1	15.9	16.1	12.9	15.2	13.0	16.1	14.6	15.1	16.5	18.3	13.9	17.0	15.4	23.8	15.8	14.0	16.8
45–50	20.7	19.4	19.7	21.6	16.7	18.0	17.5	12.1	16.6	12.1	14.3	13.8	14.1	16.6	15.0	14.0	16.6	16.9	19.6	16.4	13.3	16.4
Average																						
0–20	23.6	20.3	20.3	16.9	16.5	15.9	19.1	13.1	14.0	14.1	14.2	15.2	14.9	15.6	18.1	12.5	15.6	19.2	16.5	22.3	21.2	22.7
20–50	23.5	22.6	22.9	22.3	18.7	17.0	19.2	14.1	15.8	13.3	16.0	15.0	15.5	18.9	18.3	14.9	18.1	16.4	22.3	19.4	13.7	17.3
0–50	23.5	21.7	21.9	20.1	17.8	16.6	19.2	13.7	15.1	13.6	15.8	15.1	14.9	17.6	18.2	14.0	17.1	17.5	20.0	20.6	16.9	19.5

TABLE 7

Changes in moisture content of soil under sunflower in relation to its original moisture resources

DEPTH	MAY								JUNE										
	12	17	19	21	24	26	28	31	2	4	7	9	11	15	17	22	24	26	30
cm.																			
0–10	100	110	94	86	89	82	105	77	70	72	65	80	73	77	90	67	76	67	78
10–20	100	108	97	92	99	106	85	76	71	78	70	80	70	63	87	70	72	77	57
20–30	100	91	100	83	94	88	73	83	71	82	64	72	59	58	75	80	70	64	50
30–40	100	105	101	96	91	85	87	76	73	82	74	79	91	79	76	83	81	70	52
40–50	100	106	106	95	97	103	108	84	76	90	98	87	120	119	91	86	98	81	73

DEPTH	JULY													AUGUST								
	2	5	7	9	12	14	17	19	21	23	26	28	30	2	7	9	13	16	18	20	25	31
cm.																						
0–10	77	68	60	49	57	43	52	48	48	48	43	49	45	47	58	37	50	68	60	84	91	70
10–20	84	72	78	67	57	64	77	48	49	47	53	55	51	60	65	45	56	43	53	69	63	78
20–30	78	78	86	75	65	56	70	50	48	49	62	45	55	68	69	50	57	57	75	70	64	49
30–40	81	80	74	77	63	55	65	48	45	55	56	56	49	65	52	56	66	54	73	69	52	44
40–50	85	76	77	80	67	65	65	44	44	61	59	55	56	63	64	53	65	62	83	62	64	53

TABLE 8

Moisture content of soil under fallow, in per cent

DEPTH	APRIL		MAY									JUNE											
	22	26	10	12	17	19	21	24	26	28	31	2	4	7	9	11	15	17	22	24	26	28	30
cm.																							
0–5	33.9	32.1	29.1	24.6	27.2	22.7	24.3	25.4	23.2	22.4	21.9	21.5	19.1	19.0	21.4	21.4	27.7	21.9	21.6	17.8	19.6	21.7	19.6
5–10	30.5	31.9	28.8	28.4	27.3	24.2	23.4	27.4	25.5	22.7	21.3	21.2	23.7	20.9	21.7	22.1	26.9	23.4	24.1	19.2	17.9	22.9	18.2
10–15	20.3	22.1	25.1	27.0	26.2	25.3	25.9	24.3	20.8	17.2	17.4	20.9	16.8	19 0	21.3	22.4	27.4	18.7	20.8	17.2	15.1	23.7	17.9
15–20	22.5	21.8	29.5	26.6	22.3	20.7	18.7	19.9	17.1	17.4	16.9	18.9	17.0	15.1	16.6	21.1	21.3	17.8	16.4	17.6	18.2	20.5	15.1
20–25	16.8	16.3	23.4	21.2	20.3	19.7	18.3	21.2	18.7	17.0	17.6	16.6	18.9	15.4	16.1	15.3	22.1	17 2	16.1	15.5	18.0	18.6	17 3
25–30	16.1	19.3	20.7	19.9	19.3	19.6	18.2	20.7	19.6	15.8	16.6	17.6	18.6	14.9	16.1	17.3	19.0	18.0	16.6	15 9	17.3	17.9	18.0
30–35	18.5	21.1	21.1	19.9	20.7	20.2	17.7	23.0	19.6	22.9	19.4	18.9	18.6	15.2	16.2	15.2	18.8	17.0	16.5	16.4	15.8	17.8	15.5
35–40	15.5	15.3	20.8	19.8	23.6	21.0	17.9	19.5	18.7	16.9	18.9	19.4	17.6	14.3	17.8	18.9	18.9	16.2	15.7	16.3	15.5	18.1	15.5
40–45	14.6	19.3	18.9	17.0	18.8	18.4	17.4	17.8	16.7	16.7	17.9	16.6	16.2	15.0	17.0	16.8	18.1	15.7	14.4	15.9	15.5	17.1	15.8
45–50	15.8	19.5	17.3	16.7	16.8	19.0	15.4	17.6	17.0	16.9	16.6	17.9	17.8	15.6	14.1	14.6	17.2	15.3	15.6	14.4	14.6	17.4	14.6
Average																							
0–20	26.8	26.9	28.1	26.6	25.7	23.2	23.1	24.2	21.6	19.9	19.4	20.6	19.1	19.5	20.2	21.7	25.8	20.4	20.7	17.9	17 7	22.2	17 7
20–50	16.2	17.6	20.4	19.1	19.9	19.5	17.5	19.9	18.4	17.7	17.8	17.8	17.9	17.2	16.2	16.3	19.0	16.6	15.8	15.7	16 4	17 8	16 4
0–50	20.4	21.7	23.8	22.1	22.2	21.1	19.7	21.7	19.7	18.6	18.4	18.9	18.4	17.6	18.5	21.7	18.1	17.8	16.6	16.9	19.6	16.9	16.9

DEPTH	JULY													AUGUST								
	2	5	7	9	12	14	17	19	21	23	26	28	30	2	7	9	13	16	18	20	25	31
cm.																						
0–5	23.9	19.3	23.3	21.7	23.7	21.3	29.7	20.7	19.0	17.8	20.7	18.9	16.7	17.8	17.8	16.0	17.3	21.3	25.4	20.9	24.8	18.7
5–10	25.9	20.7	22.5	22.1	26.8	21.5	22.0	21.1	20.9	19.2	20.9	17.7	18.9	17.2	19.6	18.9	20.6	20.0	23.2	23.1	24.2	23.5
10–15	21.0	22.1	17.4	22.3	16.3	18.0	17.2	20.0	19.0	17.2	18.6	18.0	18.4	19 8	19.8	19.5	19.6	19.5	21.0	23.3	25.4	25.6
15–20	19.4	17.8	16.0	21.1	15.3	17.1	16.8	18.3	15.1	17.6	16.3	19.3	19.8	19.1	20.1	18.0	17.5	15.5	19.7	18.8	21.4	19.5
20–25	17.7	19.6	17.0	18.3	14.6	17.6	18.0	16.3	15.4	15.5	15.7	17.4	17.1	16.6	15.8	15.7	16.5	15.0	15.9	17.2	20.0	18.3
25–30	18.2	18.9	19.5	18.2	16.4	16.6	19.6	15.2	14.9	15.9	16.2	17.7	16.8	17.5	15.1	16.1	16.1	15.8	16.4	17.7	17.9	17.7
30–35	19.2	18.9	20.2	18.3	17.2	17 4	16.7	16.0	16.0	16.4	18.1	16.5	16.1	18.5	16.4	16.5	16.8	17.2	17.6	16.3	18.6	19.0
35–40	18.4	17.8	19.5	17.3	17.6	17.4	16.6	16.3	16.1	16.3	17.8	15.8	17.1	19.9	17.6	16.6	16.6	17.6	18.8	16.2	16.7	17.9
40–45	18.0	16.1	18.2	17.0	16.9	17.1	16.8	17.5	17.0	15.9	17.0	14.7	15.8	17 0	18.5	17.8	16.3	18.1	15.5	16.8	14.9	14.2
45–50	16 6	16.6	12.4	16.8	14.7	16.4	15.8	16.6	16.3	14.4	14.7	14.8	16.0	16.6	17.7	17.5	19.0	17.7	18.7	17.1	14.0	13.3
Average																						
0–20	22.5	20.0	19.8	21.8	20.5	19.5	21.9	20.0	18.5	17.9	19.1	18.7	18.4	18 5	19.3	18.1	18.2	19.1	22.3	21.5	23.9	21.8
20–50	18.0	18.6	18.1	17.6	16.6	17.1	17.3	16.3	15.9	15.7	16.6	16.1	16.5	17.7	16.8	16.7	16.9	16.9	17.1	16.9	17.0	16.7
0–50	19.8	18.8	18.8	19.0	18.1	18.0	18.9	17.8	16.9	16.6	17.6	17.2	17.2	18.0	17.8	17.3	17.7	17.8	19.2	18.7	19.8	18.8

TABLE 9

Changes in moisture content of soil under fallow in relation to its original resources

DEPTH	APRIL		MAY									JUNE											
	22	26	10	12	17	19	21	24	26	28	31	2	4	7	9	11	15	17	22	24	26	28	30
cm.																							
0–10	100	99	90	82	84	72	73	82	75	70	67	66	66	62	67	67	85	69	70	70	57	57	58
10–20	100	98	128	125	113	107	104	103	88	81	80	93	79	79	88	101	114	103	85	87	81	77	77
20–30	100	108	134	125	120	119	111	127	116	100	104	104	114	92	98	98	125	111	107	100	96	107	107
30–40	100	107	123	116	130	121	105	125	112	107	112	112	107	...	100	100	110	105	98	95	96	92	92
40–50	100	128	119	110	114	123	108	116	110	110	113	113	112	100	102	102	113	113	102	99	100	99	100

DEPTH	JULY													AUGUST								
	2	5	7	9	12	14	17	19	21	23	26	28	30	2	7	9	13	16	18	20	25	31
cm.																						
0–10	80	62	70	68	78	66	78	65	62	57	78	55	55	54	52	58	54	59	64	75	68	76
10–20	94	93	78	101	74	82	79	89	79	81	81	89	89	91	78	93	87	96	82	95	98	109
20–30	109	117	109	111	95	104	115	96	92	98	106	103	104	102	94	97	99	94	101	106	109	115
30–40	110	107	116	105	102	102	98	95	95	95	95	98	113	95	100	98	98	102	101	95	104	108
40–50	110	107	107	111	103	109	107	112	108	100	103	97	105	111	114	119	114	114	118	114	111	110

the changes in the moisture content in each layer for the entire period of observations.

DISCUSSION OF THE DATA OBTAINED

1. Winter rye begins its growth in early spring with a well-established root system, which gives the rye a chance to utilize the water resources present in the soil. For this reason it makes a considerable part of its growth in a very short period (tables 2 and 3). The first determination of the moisture content of the soil under winter rye was made on April 22, the next on April 26, and the third on May 10. During the period from May 6 to 9, 52.8 mm. of rain fell. The determination of the moisture content made on May 10, however, showed, not an increase over, but a decrease from the determination previously made. In the layer from 0–100 cm. there was an increase in moisture; layers 10–20 and 20–30 cm. showed no change; layers 30–40 and 40–50 cm. showed a decrease. This indicates that during this time winter rye is utilizing, by means of its well developed root system, the water from the entire depth of the layer investigated. The rain that fell during the period could not meet the moisture requirements of the winter rye which, therefore, used the water resources already present in the soil.

During the following days it continued to rain, giving in one day, on May 13, 30.5 mm. When a determination was made four days later, a general increase in moisture content for the entire depth of the layer was noticed. The picture is different when we examine the separate layers. The smallest addition of moisture was found in layer 0–10 cm. No change in moisture content occurred in layer 10–30 cm., whereas the moisture content of layer 30–50 cm. increased. The explanation is that 87 mm. of rain fell, and because of the original water resources in the upper soil layer there was a slight percolation of rain water through the layer under consideration. The precipitation satisfied the plant requirements for water and a part of it increased the moisture content of the upper layer of the soil. A moisture determination on May 17 showed that the water resources from the rain in the upper layer of the soil was completely utilized by the plants. The additional moisture obtained by layer 40–50 cm. remained intact. During the days following, this moisture was also utilized.

After the rains from May 6 to 14, a dry spell occurred, which continued to June 6. It is especially interesting to follow the expenditure of water by the winter rye during this period. During this time the rye developed 63 per cent of the dry weight of tops and accumulated at the end of this period 85 per cent of the weight of dry matter of the total yield.

It is necessary to point out the rapid utilization of water during this period. During the 18 days from May 17 to June 5, with comparatively cool weather, a hectare of land occupied with winter rye used 740 tons of water. This decreased the moisture content of the 0–50 cm. layer from 24.7 per cent to 11.8 per cent. The last figure on the moisture content of the soil approaches the figure of the so-called "dead resources" of the water in such soil types.

The expenditure of water during this time was constant and the moisture gradually decreased. Although on May 19 the layers from 0–10 and from 10–20 cm. showed a decrease in water, the moisture content of layer 20–30 and 30–40 cm. increased; the moisture content of layer 40–50 cm. remained the same. Moisture determinations made later showed that the decrease in water took place from all the layers but in less degree from the deeper-lying layers. Layer 0–10 cm. had a moisture content of 7.5 per cent; it increased gradually wtih the depth.

The moisture content in layer 40–50 cm. does not go higher than the moisture contents for the other layers, as was expected; it is between those of 10–20 and 20–30 cm. The explanation is that this layer was not saturated with the rainwater during the month of May and therefore it lost moisture from its original resources, whereas the other layers in the beginning of the period utilized the moisture from the rainfall.

Layers 0–10 and 10–20 cm. quickly lost the additional water resources. Layers 20–30 and 30–40 cm., which conserved the rainwater, began to lose their original water resources only in the second half of the period.

From June 6, the weather changed. Light, frequent rains fell. The tempo of the water expenditure from the soil slowed down, which was in concordance with the slowing down of the development of the winter rye.

After 15 days a maximum accumulation of dry matter was noticeable. During this time a translocation of the nutrient substances takes place from the leaves and stems into the head. The course of the moisture content in the soil during the period of ripening of the winter rye shows very distinctly each falling rain, and this in turn shows how well the soils of the experimental field take up the water. After a few days these additional water resources were lost only to be restored again by the following rains. In itself these light rains were of no interest to the investigator but they complicated the general picture of water utilization by the winter rye for the period, making of doubtful value the number which shows the expenditure of water by the winter rye.

It is important to note that all the rains caused a noticeable increase in the moisture content in the upper layers. At the same time a slight addition of moisture could also be observed in the deeper layers of the soil. The reason for this is not well understood and it is desirable to investigate it more thoroughly.

2. The observations on the moisture content of the soil with spring wheat (table 4 and 5) were begun on May 10. On May 13, 30 mm. of rain fell and the samples taken on May 17 showed the maximum water content for the entire period of observations. From May 13 to June 6 there was no rain. As has been mentioned, the winter rye utilized completely the water resources in a 50-cm. layer of the soil. This was not true of the spring wheat. Although the moisture content of the soil during this period at a depth of 50 cm. decreased under the spring wheat by 7 per cent, still the water resources

in the soil on June 6 amounted to 18 per cent of the dry weight of the soil. The spring wheat slowly developed during this time; it accumulated only 7 per cent of the weight of the dry matter of the yield; it is impossible, therefore, to ascribe the loss of water entirely to its utilization by the wheat. Undoubtedly a large portion of this loss of water was due to the direct evaporation of the moisture from the surface of the soil. This is corroborated by the figures on the loss of moisture by the respective layers of soil during the same period. Whereas the moisture content of layers 20–30 and 30–40 cm. remained almost constant, layers 10–20 and 0–10 cm. lost 50 per cent of their original moisture resources. During the next ten days, from June 5 to 15, the spring wheat developed more rapidly. The weight of the dry matter increased three times but the moisture content of the soil remained unchanged because of the 33.1 mm. of rain. Apparently this water served the spring wheat for its development leaving intact the original water resources. After June 15 another dry spell occurred which lasted to June 26. During this time the spring wheat kept developing, satisfying its moisture requirements from the water resources originally found in the soil. The moisture content of the 50-cm. layer in the soil dropped from 18 per cent to 10 per cent; in other words the spring wheat utilized almost all of the water resources available from the entire layer. At the end of the period, the upper layers of the soil up to 20 cm. contained only 30 per cent of their original water resources; layer 20–30 cm. contained 40 per cent; layer 30–40 cm., 50 per cent; and only layer 40–50 cm. preserved more than 60 per cent.

From June 27 to July 1, daily rains occurred giving a total of 19.1 mm. of water. These increased the moisture content of the soil, and the water added in this way could be found in the layer up to 20 cm.; the increase in moisture of the deeper layers, 20–30 and 30–40 cm., remains unexplained, as in the case of the winter rye.

The moisture content of the soil layer investigated dropped at the end of July to a value equal to the one before the rains at the end of June. The drop was slower than in June. Apparently the spring wheat, having developed a good root system by this time, satisfied its moisture requirements by getting the water from the deeper soil layers. This is very well illustrated by determinations of moisture content to a depth of 100 cm.

DEPTH	TIME OF OBSERVATION	
	July 1	July 26
cm.	*per cent*	*per cent*
50–60	15.0	9.7
60–70	13.3	10.6
70–80	10.2	6.9
80–90	10.2	5.9
90–100	10.7	6.3
Average	11.9	7.8

The loss of moisture in layer 50–100 cm. during July was equal to 4.1 per cent.

3. The sunflower developed slowly in the first period of its vegetation. Up to June 24 it contained only 6 per cent of its total dry matter. The maximum moisture content in the soil was noticed on May 17 after the rains; gradually the moisture content decreased. A part of this decrease must be attributed to the evaporation from the soil surface. The changes in moisture content of the soil by layers was as follows: The moisture content of layer 40–50 cm. remained unchanged; the moisture content of layer 30–40 cm. lost 15 per cent of its original water resources; layers 0–10, 10–20, and 20–30 cm. lost about 30 per cent of their original water resources. From June 2 to 26 the moisture content remained constant; the water lost was compensated by the rains that fell during the period. From June 24 to 30 a rapid lowering of the moisture content of the soil was noticed. This corresponds to the intensive development of the sunflower during this period. During the 10 days from June 24 to July 3 the weight of the dry matter increased 400 per cent; about 20 per cent of the total dry matter of the crop was produced during this period.

The rains that fell toward the end of June brought the moisture content of the soil on July 2 to the level of June 24. During the month of July the moisture content dropped rapidly because during this month the greatest development of the sunflower crop took place; on July 24, 85 per cent of the dry matter of the total crop was found. It is important to note that the loss of water from the individual layers of the soil was uniform during this period. It is apparent that the sunflower utilized the moisture resources of the soil layer throughout its 50-cm. depth.

No lowering of the moisture content of the soil under sunflower was noticed during August. The rains during this month allowed it to complete the development of the dry matter in the crop without using the original water resources of the soil. Toward the end of the month a slight increase in the moisture content was noticed. At the end of the vegetation period the soil under sunflower still retained a considerable store of water.

4. Observations on the change in moisture content in the plot under fallow were begun in the early spring and were continued to the time when the winter rye came up. The trend of the moisture content under fallow may be studied from tables 8 and 9. In May, the moisture was about the same as on the plots occupied with spring wheat and sunflower. The moisture content gradually decreased, reaching the limit of 18–19 per cent of the total weight of the soil. After that the moisture content in the plot under fallow was uniform throughout the summer. The rains increased it primarily in layers 0–10 and 10–20 cm.; this increase, however, did not last very long and a few days after the rains this moisture was evaporated. The moisture content in layers 20–30, 30–40, and 40–50 cm. remained unchanged throughout the summer. At the time of planting the winter rye, August 25,

the soil of early fallow contained the same amount of moisture as at the time of the first determination in the spring. It is clear that the rains which fell during the summer of 1926, even though twice the normal rainfall, did not allow an accumulation of the moisture in the soil. The fallow thus retained the moisture which it received during the fall and early spring.

CONCLUSIONS

1. The intensive utilization of the water resources of the soil by winter rye begins from the moment of its spring awakening. The expenditure of water is so great that the rains that fell in May, 87 mm., only maintained the moisture content of the soil at a uniform level.

The expenditure of water by the winter rye began with the surface layers of the soil, and the accessible resources throughout a depth of 50 cm. were utilized during the dry period from May 13 to June 5, during which time 65 per cent of the dry matter of the crop was produced. The final development of the winter rye has been made at the expense of the July rains, thus the rôle of the summer rains in making up the crop of rye has been clearly noted in 1926.

2. The lowering of the moisture content observed under spring wheat in May must be attributed to the surface evaporation of water. The period of utilization of moisture resources under spring wheat has been shifted two weeks when compared with the winter rye. During the 11 days of rapid growth the moisture content of the 50-cm. layer of the soil fell to the so-called "dead resources." Later, the spring wheat satisfied its moisture requirements partly from the water of the rains that fell, and partly from the resources of the deeper layers of the soil.

3. After harvesting the winter rye and the spring wheat, the soil, to a depth of 100 cm., was dry to the point of its so-called "dead resources of moisture."

4. The course of the moisture content of the soil under sunflower during the first part of its vegetation period was similar to that of the plot on the fallow. A lowering of the moisture content was noticed only from June 24 to 30 during the intensive development of the sunflower. A still greater expenditure of water was noticed in July when the greatest portion of the dry matter was produced. Almost the entire crop of sunflower in 1926 was produced with the aid of the rains during the vegetation period.

5. The soil under fallow lost its water during the spring in the same way as the soils under spring wheat and sunflower. It reached a limit of 18 per cent. The rains during the summer did not increase the moisture content of the soil under fallow. Thus the soil just maintained its water resources from the previous fall and early spring and did not conserve the moisture from the summer rains.

ACTINOMYCES ACIDOPHILUS N.SP.—A GROUP OF ACIDOPHILUS ACTINOMYCETES ISOLATED FROM THE SOIL

H. L. JENSEN

State Laboratory of Plant Culture, Lyngby, Denmark

Received for publication October 17, 1927

During the course of some studies on the microflora of normal and partially sterilized soils, a remarkable organism, apparently an actinomyces, was seen in a few cases to develop on the acid agar medium for counting fungi (dextrose-asparagin-agar of pH 3.8 to 4.0). First, the organism appeared in plate cultures from a heath soil (dry peat) of pH 3.85 in numbers amounting to 100 to 200 colonies per plate in a 1:2000 dilution; when this soil was subjected to liming, the organism disappeared totally within 15 days. Later similar organisms appeared in plate cultures from two soils partially sterilized by toluene—a heath soil of pH 4.12 and a forest soil (consisting almost entirely of organic matter) of pH 3.34. The organisms grew readily on the acid agar medium, producing in 3 to 4 days small white, compact colonies possessing all the morphological characters of a typical actinomyces; they could not be traced upon the neutral medium for counting bacteria and actinomycetes (dextrose-casein-agar of pH 6.5 to 6.6). Attempts to isolate the organisms on the media commonly used for cultivating actinomycetes (Czapek's agar, nutrient agar with or without dextrose or starch) failed invariably, whereas isolation was easy and successful when the colonies were transferred to slants of the acid dextrose-asparagin-agar. The organisms thus seemed to be able to live only in acid media, a property hitherto unknown to members of the group of actinomycetes (6, 5, 1). For this reason, they seemed to deserve a closer study. In this study, 4 strains of the organism were compared; two strains (nos. 1 and 2) were isolated from the forest humus, one (no. 3) from heath soil of pH 4.12, and one (no. 4) from heath soil of pH 3.85.

MEDIA USED

The following media were used:

1. *Dextrose agar.* Dextrose, 20.0 gm.; asparagin, 2.0 gm.; KH_2PO_4, 2.0 gm.; $MgSO_4$, 0.5 gm.; NaCl, 0.5 gm.; $FeCl_3$, 0.1 gm.; Agar, 25.0 gm.; distilled water, 1000 cc. Reaction adjusted to pH 3.8 to 4.0.

2. *Starch agar.* Soluble starch, 10.0 gm.; $(NH_4)_2SO_4$, 2.0 gm.; KH_2PO_4, 1.0 gm. $MgSO_4$, 0.5 gm.; NaCl, 0.5 gm.; $FeCl_3$, 0.1 gm.; Agar, 25.0 gm.; distilled water, 1000 cc. Reaction adjusted to pH 3.8 to 4.0.

3. *Gelatin.* 15 per cent of "Gold Label" gelatin in distilled water; reaction either unchanged (about pH 5.4) or adjusted to pH 4.4.

4. *Potato plugs.* Either plain or acidified by boiling the plugs, before sterilization, in a 0.5 per cent KH_2PO_4 solution.

MORPHOLOGICAL CHARACTERS

Vegetative mycelium on dextrose and starch agar of the common actinomyces type—profusely branched, 0.6 to 0.8μ thick hyphae with homogenous protoplasm and no visible septa (pl. 1, fig. 1).

Aerial mycelium. In strains 1 and 2, hyphae rather short, 1.0 to 1.2μ thick, not very much branched, straight, occasionally forming a few short, sinistrorse spirals; in strains 3 and 4, hyphae longer, 1.0 to 1.2μ thick, somewhat branched; end branches form very numerous, fine, regular, sinistrorse spirals of a closed type; the spirals (on dextrose agar) are rather short in strain 3 and long (up to 8 to 10 turns) in strain 4 (pl. 1, figs. 2–4).

Spores arise by division of aerial hyphae in oidia-like chains; short oval in all four strains, 1.0 to 1.2 by 1.2 to 1.5μ (pl. 1, figs. 5–8). The mode of spore-formation resembles that of *Actinomyces Madurae*, as figured by Ørskov (2).

CULTURAL CHARACTERS

1. Dextrose agar. 25°C. Good growth. *Substratum mycelium* raised, somewhat wrinkled, colorless in young cultures, later changing to faint yellowish, brownish, or reddish-gray tinges, sometimes (strain 4) becoming finally dark olive-brown.

Aerial mycelium appears sooner or later, most abundant in strains 1 and 2, sometimes almost absent (strain 3); thin, either in patches or covering the whole growth, first white, later turning light gray or yellowish-brown.

Soluble pigment most pronounced in strain 4, first yellowish, later olive-green; in the other strains only light yellowish. Pigment formation, upon the whole, is variable and little characteristic.

Drop formation. Strains 3 and 4 show a profuse secretion of drops of a slimy, colorless fluid.

2. Starch agar. 25°C. Good growth. In young cultures: substratum mycelium flat, smooth, colorless. Aerial mycelium abundant, smooth, snow-white. No pigment. Old cultures (30 days): strains 1 and 2 unchanged; strains 3 and 4, growth assuming a yellowish color, faint yellow soluble pigment.

3. Gelatin. 20°C. All 4 strains similar at both reactions. After 10 days: growth very scant, thin, colorless, semi-transparent; no aerial mycelium; no soluble pigment; very little liquefaction. After 30 days: growth a little stronger, otherwise unchanged; liquefaction proceeds extremely slowly.

4. Potato plug. (25°C. 10 days.) a. Plain potato: growth good (strains 1 and 2) to excellent (strains 3 and 4) raised, folded, cream-colored (strain 2) to yellowish gray (strains 3 and 4) or rust-brown (strain 1). Aerial mycelium absent or only traces of white. No discoloration of the plug. b. Acidified potato: as on plain potato, but excellent growth of all strains.

After 30 days: all cultures similar: abundant growth of a dirty yellowish-gray color; no aerial mycelium or only traces of white, no discoloration of medium.

Other media. Czapek's agar, nutrient agar, milk, and plain broth: no growth.

REACTION REQUIREMENTS

To study the ability of the organisms to grow at different hydrogen-ion concentrations, the following solution was prepared: dextrose, 20.0 gm.; asparagin, 2.0 gm.; citric acid, 4.0 gm.; KH_2PO_4, 2.0 gm.; $MgSO_4$, 0.5 gm.; NaCl, 0.5 gm.; $FeCl_3$, 0.1 gm.; H_2O, 1000 cc. This solution was divided into several lots and the reaction altered by the addition of hydrochloric acid, sodium hydroxide, and distilled water to equal volume. The solutions were then distributed to test tubes in portions of 10 cc., plugged and sterilized. The composition and reaction of the different solutions are shown in table 1.

TABLE 1

Composition of dextrose-asparagin-solutions of different hydrogen-ion concentrations

NUMBER	ADDITION PER 100 CC. OF SOLUTION:				pH VALUE	
	1 *N* HCl	0.1 *N* HCl	1 *N* NaOH	H_2O	Before sterilization	After sterilization
	cc.	*cc.*	*cc.*	*cc.*		
1	1.5	....	...	8.5	1.98	1.99
2	...	10.0	...	...	2.35	2.36
3	...	5.0	...	5.0	2.54	2.57
4	...	....	...	10.0	2.75	2.76
5	...	....	1.0	9.0	3.23	3.34
6	...	....	1.5	8.5	3.70	3.75
7	...	....	2.0	8.0	4.12	4.22
8	...	....	2.5	7.5	4.54	4.61
9	...	....	3.0	7.0	4.86	4.86
10	...	....	3.5	6.5	5.28	5.32
11	...	....	4.0	6.0	5.83	5.84
12	...	....	5.0	5.0	6.56	6.50

The solutions were inoculated with aerial mycelium from dextrose agar cultures of the four strains and incubated for 30 days at 25 to 26°C. After that period the relative growth was noted and the changes in reaction were measured.[1] Table 2 gives the results, which clearly point out the acidophilous character of the organisms. With regard to their ability to resist high hydrogen-ion concentrations, they are comparable to the fungi, the growth first being hindered at pH 2.6 to 2.8. Still more striking is their rigid requirement of a sufficiently *acid* reaction, the growth declining at pH 5.3 to 5.8 and being checked or greatly delayed at pH 6.5. A rather broad optimal zone seems to exist, at pH 3.3 to 3.8 for strains 1 and 2 and at pH 4.2 to 5.3 for strains 3 and 4. Attention should be called, however, to the fact that limits such as

[1] Measurements of hydrogen-ion concentration were carried out by means of the quinhydrone electrode, except in the case of agar media, where the colorimetric method was used.

these may have no absolute meaning; for example, all four strains grow freely on plain potato plugs, although this medium is but slightly acid, and

TABLE 2

Relative growth and changes in reaction by 4 strains of acidophilous actinomycetes*

INITIAL pH		STRAIN 1		STRAIN 2		STRAIN 3		STRAIN 4	
		Growth	Final pH	Growth	Final pH	Growth	Final pH	Growth	Final pH
1.99	a	0	....	0	....	0	....	0	....
	b	0	....	0	....	0	....	0	....
2.36	a	0	....	0	....	0	....	0	....
	b	0	....	0	....	0	....	0	....
2.57	a	0–1	2.63	0	....	0–1	2.66	0	....
	b	1	2.65	0	....	1	2.68	0	....
2.76	a	4	3.06	0–1	....	2	2.92	0–1	2.93
	b	5	3.20	0–1	....	4	3.23	0–1	2.86
3.34	a	5	4.26	5	4.29	4	4.16	3	3.79
	b	5	4.40	5	4.30	4	4.57	4	3.84
3.75	a	5	4.77	(3)	(3.88)	4	4.37	3	4.01
	b	5	4.73	5	4.99	4	4.54	3	4.08
4.22	a	5	4.80	5	4.73	5	4.81	4	4.45
	b	3	4.27	5	5.28	5	4.90	4	4.47
4.61	a	3	4.83	4	4.95	5	5.11	5	4.82
	b	2	4.59	4	4.91	5	5.03	5	4.82
4.86	a	3	5.01	4	5.21	5	5.26	5	5.20
	b	2	5.00	4	5.15	5	5.29	5	5.22
5.32	a	1	5.34	3	5.40	5	5.44	5	5.42
	b	1	5.34	2	5.39	5	5.40	5	5.44
5.84	a	1	5.82	0–1	5.96	3	5.65	4	5.44
	b	1	5.88	0–1	6.01	3	5.65	3	5.82
6.50	a	0	6.50	0	....	1	6.20	1	6.50
	b	0	6.48	0	....	1	6.31	1	6.48

* In this and the following, the growth is designated by the following figures: 0 = no growth; 0–1 = growth barely perceptible; 1 = very scant growth; 2 = rather scant growth; 3 = fair growth; 4 = good growth; 5 = excellent growth.

strain 4 would grow in glycerine-peptone-broth only at pH values between 3.56 and 5.29. The nature of the medium, thus, may greatly affect the ability of the organism to tolerate high and low hydrogen-ion concentrations.

Further, it is seen that the reaction of the medium is almost constantly changing toward less acid values (except in the case of a few of the least acid solutions), and that the change is to a certain extent proportional to the amount of growth. This change in reaction is probably due to the splitting off of ammonia from the asparagin, perhaps also to the absorption of citric and phosphoric acid.

BIOCHEMICAL FEATURES

1. Utilization of different nitrogen compounds. The following solution was used as a basis: Dextrose, 20.0 gm.; KH_2PO_4, 2.0 gm.; $MgSO_4$, 0.5 gm.; NaCl, 0.5 gm.; $FeCl_3$, 0.1 gm.; H_2O, 1000 cc. Reaction adjusted to pH 4.0. The different nitrogen compounds to be tested were added in concentrations from 0.2 to 1.0 per cent, and the solutions were distributed, sterilized, inoculated, and incubated as before. The results are given in table 3.

TABLE 3

Utilization of different nitrogen compounds by acidophilous actinomycetes

STRAIN NUMBER		GROWTH ON DEXTROSE SOLUTION +								
		No nitrogen	0 2 per cent KNO_3	0 2 per cent $(NH_4)_2SO_4$	0 2 per cent NH_4 tartrate	0 2 per cent urea	0 2 per cent glycine	0 2 per cent asparagin	1 0 per cent peptone	1 0 per cent gelatin
1	a	0–1	3	4	5	5	5	5	3	4
	b	0–1	4	4	5	5	5	5	3	4
2	a	1	5	3	3	5	4	5	2	4
	b	1	5	3	4	5	4	5	3	4
3	a	0–1	0–1	3	4	5	4	4	3	2
	b	0–1	0–1	4	4	5	4	4	3	2
4	a	0–1	0–1	4	3	4	4	4	3	2
	b	0–1	0–1	4	4	4	4	5	3	2

It is seen that free nitrogen is not fixed; nitrates are of no value to strains 3 and 4; for strains 1 and 2 they form an excellent source of nitrogen. Ammonium sulfate, ammonium tartrate, urea, glycine, and asparagin are all good to excellent sources of nitrogen. But the proteins (peptone and gelatin) are inferior to the compounds named above as sources of nitrogen—a remarkable difference from the case with other actinomycetes. This fact is explained through the remarkably weak proteolytic power of the organisms in question.

2. Utilization of different carbon compounds. In this instance the following solution was used as a basis: $(NH_4)_2SO_4$, 2.0 gm.; KH_2PO_4, 2.0 gm.; $MgSO_4$, 0.5 gm.; NaCl, 0.5 gm.; $FeCl_3$, 0.1 gm.; H_2O, 1000 cc.; pH 4.0. The different carbon compounds were added in amounts of 1.0 per cent, except cellulose

which was supplied as a strip of pure Swedish filter paper in carbon-free solution. When salts of organic acids were used, the solutions were titrated back to pH 4.0. The arrangements of the experiment otherwise as before (30 days, 25°C.). Table 4 gives the results.

With regard to carbon requirements, the organisms are seen upon the whole to resemble other actinomycetes. Calcium malate is a comparatively good source of carbon, whereas calcium lactate is valueless. Glycerine is fairly well utilized by all four strains; mannite is not utilized by strains 1 and 2, but forms a good nutrient for strains 3 and 4. Dextrose, starch, and especially saccharose form the best sources of carbon for all four strains, whereas inulin and cellulose seem to be of no value at all.

3. Proteolytic activity. Strains 1 and 4 were grown in the following medium: Riedel's peptone, 20.0 gm.; Dextrose {‡, 20.0 gm.; KH_2PO_4, 2.0 gm.;

TABLE 4

Utilization of different carbon compounds by acidophilous actinomycetes

STRAIN NUMBER	GROWTH ON $(NH_4)_2SO_4$ SOLUTION +									
	No carbon	Ca malate	Ca lactate	Glycerin	Mannite	Dextrose	Saccharose	Inulin	Starch	Cellulose
1	0–1	2	0–1	3	0–1	4	5	0–1	5	0–1
	0–1	2	0–1	3	0–1	4	5	0–1	5	0–1
2	0–1	2	0	3	0	3	3	0–1	3	1
	0–1	3	0	3	1	3	4	0–1	4	1
3	0–1	3	0–1	3	3	3	5	1	3	1
	0–1	3	0–1	3	4	4	5	1	4	1
4	0–1	3	0	3	3	4	4	1	3	0–1
	0–1	3	0	2	3	4	5	1	4	0–1

$MgSO_4$, 0.5 gm.; NaCl, 0.5 gm.; $FeCl_3$, 0.1 gm.; H_2O, 1000 cc. The solution was distributed in portions of 75 cc. in 200 cc. Erlenmeyer flasks, sterilized, inoculated and incubated at 25°C. For comparison a strain of *Aspergillus niger*, isolated from greenhouse soil and known to possess a strong proteolytic power, was grown in the same medium. After 25 days the reaction and the amounts of NH_3–N (by distillation with MgO) and NH_2–N (by Sørensen's formaldehyde method) were determined. The results are found in table 5.

It will be seen at once that the proteolytic power of the actinomycetes is in no way comparable to that of *Aspergillus niger*, as might also be expected from the comparatively poor growth of the actinomycetes on peptone and gelatin as sources of nitrogen (table 3) In this case, too, the growth was scant, consisting of many small, round colonies on the bottom of the flask;

the growth of *Aspergillus niger* was good upon the solution without dextrose, and enormously vigorous on the solution with dextrose. Dextrose is seen to have a slightly depressive effect on the proteolysis by the actinomyces and to act similarly upon *Aspergillus niger*, substantiating Waksman's (4) results. Upon the whole, these actinomycetes must be said to possess only a very weak proteolytic power, weaker than that of actinomycetes in general, the majority of which are at least comparable to the fungi as far as proteolytic activity is concerned (4).

5. *Diastatic activity.* Plate cultures were made upon starch-ammonium sulfate-agar of pH 4.0. After 6 days' incubation at 25°C. the plates were covered with iodine solution; all strains showed enzymatic zones around the colonies—12 to 15 mm. broad in strain 2, 8 to 10 mm. in the others. Like

TABLE 5

Comparative proteolytic power of acidophilous actinomycetes and Aspergillus niger

		ACTINOMYCES STRAIN 1		ACTINOMYCES STRAIN 4		ASPERGILLUS NIGER		CONTROL	
− dextrose	NH_3-N*	3.5 3.5	3.5	7.0 7.7	7.4	208.6 207.2	207.9	0.0 0.0	0.0
	Formol-titrating N*	28.0 28.0	28.0	30.8 30.1	30.5	191.8 189.3	190.6	21.8 20.6	21.2
	Final pH	3.62		3.74		4.86		3.53	
+ dextrose	NH_3-N*	3.8 3.5	3.7	4.2 4.2	4.2	179.2 177.8	178.5	0.0 0.0	0.0
	Formol-titrating N*	24.5 25.9	25.2	25.9 26.6	26.3	142.8 141.4	142.1	21.0 21.0	21.0
	Final pH	3.56		3.58		6.44		3.53	

* Milligrams per 100 cc. of medium.

other actinomycetes the organisms in question thus exhibit a good diastatic activity. In solution, the activity seemed less strong, reaction with iodine still being very strong after 30 days.

6. *Inversion of cane sugar.* The cultures in saccharose solution (table 4) were tested for their reduction of Fehling's solution; only traces of reducing sugars, not greater than the quantity present in the uninoculated medium, were present. Upon boiling with sulfuric acid the reduction became very strong. Invertase thus does not seem to be secreted.

7. *Reduction of nitrates.* The KNO_3 cultures from table 3 were tested, at the end of the experiment, for their content of NO_2 by Gries's reagent. Strains 1 and 2, utilizing nitrates, showed a very faint reaction; strains 3 and 4, none.

SYSTEMATIC POSITION

The organisms here dealt with possess all the morphological and partly also the physiological characters of most actinomycetes, but are sharply differentiated from all other members of this group of microörganisms by their requirement of acid reaction. As the four strains fall into two apparently well-defined subgroups, distinguished by the almost absent and abundant spiral formation, and the positive and negative utilization of nitrate and mannite, the two subgroups were thought at first to represent two distinct species. It must be borne in mind, however, that the actinomycetes are among the most variable of all living organisms, and the constancy of the different characters used as a basis for the separation into "species" is not too well known, so that in speaking of actinomycetes, the term "species" should be used with the very greatest caution. Views such as these are strongly emphasized in some of the more recent works on actinomycetes, such as that of Lieske (1), who completely discards the classification into species, and of Waksman (3, p. 170) who substitutes for "species" the term "species-groups" (". . . . a distinct separation into species is almost next to impossible, because new forms will be found which will tend to bring two distinct species together; it is therefore much more advisable in the study of these organisms, to separate them into species-groups where the species resembling one another in their metabolism would fall"). In the sense used by Waksman, the organisms here described may be regarded as a new "species-group," to which the name *Actinomyces acidophilus* may justly be given. This new species-group can briefly be characterized thus:

Vegetative mycelium. 0.6 to 0.8μ thick hyphae with homogenous protoplasm and no visible septa.

Aerial mycelium. 1 0 to 1.2μ thick, more or less branched hyphae forming either very few or very numerous sinistrorse spirals.

Spores. Short oval, 1.0 to 1.2 $\times$ 1.2 to 1.5μ, arise by division of aerial hyphae in oidia-like chains.

Growth occurs only in acid media, from pH about 2.6 to 2.8 to about 5.8 to 6.5, with an optimal zone from pH 2.8 to 3.3 or pH 4.8 to 5.3. No brown pigment in protein-media.

Utilization of nitrogen compounds. Nitrate is sometimes utilized and sometimes not; ammonium salts, urea, and amino acids are good sources of nitrogen; proteins are less favorable.

Utilization of carbon compounds. Calcium malate, glycerine, dextrose, saccharose, starch, and to some extent mannite are fair to excellent sources of carbon; calcium lactate, inulin, and cellulose are almost valueless.

Proteolytic activity. Very weak.

Diastatic activity. Good.

Inversion of cane sugar. Negative.

Reduction of nitrate. None or trace.

Habitat. Acid humus soils.

SUMMARY

Four strains of acidophilus actinomycetes were isolated from 3 acid humus soils (pH 3.4 to 4.1). They were found to represent a new species-group, to which the name *Actinomyces acidophilus* was given; they are morphologically typical actinomycetes, but are sharply differentiated from all other actinomycetes by their ability to live only in acid media.

REFERENCES

(1) LIESKE, R. 1921 Morphologie und Biologie der Strahlenpilze. Berlin.

(2) ØRSKOV, J. 1923 Investigations into the Morphology of the Ray Fungi. Copenhagen.

(3) WAKSMAN, S. A. 1919 Cultural studies of species of actinomycetes. Soil Sci. 8: 71.

(4) WAKSMAN, S. A. 1920 Studies in the metabolism of actinomycetes; III. *Jour. Bact.* 5: 1.

(5) WAKSMAN, S. A. 1922 The influence of soil reaction upon the actinomycetes causing potato scab. *Soil Sci.* 14: 61.

(6) WAKSMAN, S. A., AND JOFFE, J. S. 1920 Studies in the metabolism of actinomycetes; IV. *Jour. Bact.* 5: 31.

PLATE 1

FIG. 1. Strain 1, aerial mycelium, 10 days at 25°C. × 110. (Living material.)

FIG. 2. Same, with spiral formation.

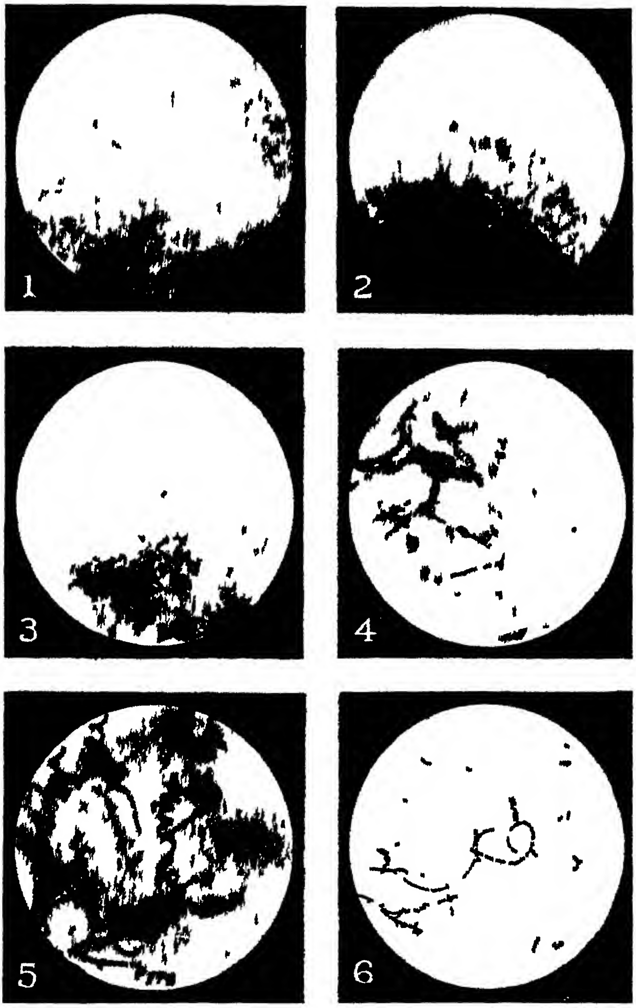
FIG. 3. Strain 4, aerial mycelium, 10 days at 25°C. × 110. (Living material.)

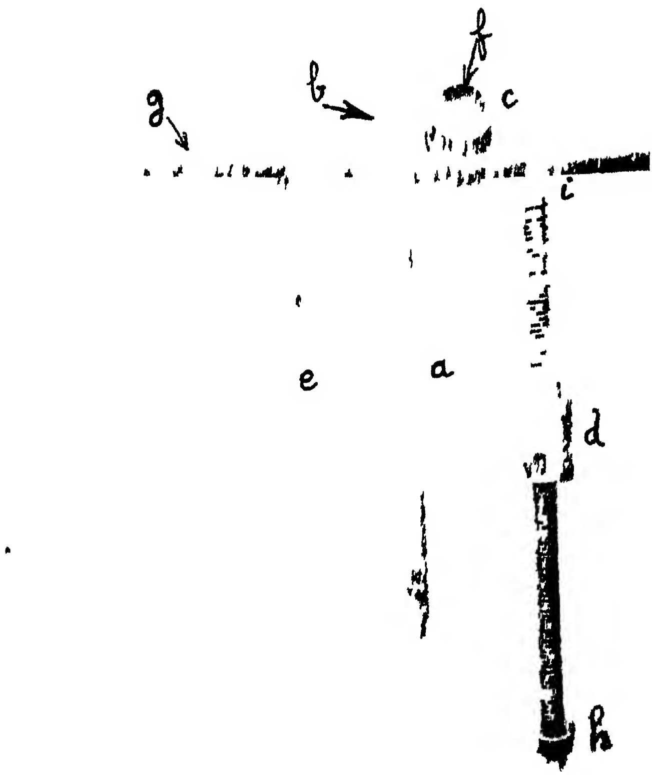
FIG. 4. Strain 1, spore formation in aerial mycelium, 10 days at 25°C. × 330. (Living material.)

FIG. 5. Strain 4, spore formation in aerial mycelium, 10 days at 25°C. × 330. (Living material.)

FIG. 6. Strain 1, spore-forming aerial hyphae, 12 days at 25°C. × 560. (Kisskalt.)

All photographs are made by means of the Zeiss Phocu apparatus. Cultures upon dextrose-asparagin-agar.


1
2
3
4
5
6



KOPP'S SOIL SAMPLER

A NEW SOIL SAMPLER

A. KOPP[1]

Station Agronomique de la Guadeloupe

Received for publication July 16, 1926

The writer having undertaken a soil survey of the sugar cane lands of Guadeloupe (French West Indies) has been led to devise the instrument described below.

This soil sampler consists of a steel tube *a* 5 cm. in diameter by 2½ mm. thick, with a bevelled bottom. A T-piece handle, made of a smaller pipe, is soldered, by the oxyacetylene flame, on the main tube. At 4 cm. below the top of the sampler are firmly welded in at *b*, two catches diametrically opposite each other. These catches are cylindrical and 1 cm. in diameter by 1 cm. long.

The bronze hood *c* loosely covers the top of *a*. It is hollowed and a groove is provided. The hood is lined with hardwood, antifriction metal, or any other substance moderately soft and non-springy, because this groove receives the upper edge of *a*. The edges of *c* must fit down below *b* and should be hollowed out to give way to *b*.

To take a sample, put *c* on the top of *a;* hold *a* vertically and strike on *c* with a sledge. It is better to strike moderate and repeated blows than a few heavy ones. When the sampler has sunk enough, cease to strike, and slue with the handle. Then pull the sampler out of the soil.

When the sampler is out of the soil, remove *c* and place *d* on the top of *a*. The spurs *b* will enter the slots of *d* and hold the hood firmly. With *e* on *i* the screw is turned and the earth is forced out by the piston *h*. The screw has square threads and is 25 mm. in diameter. The inner diameter of *a* is equal to that of the piston.

This instrument facilitates the taking of samples of soil to a depth of 1 meter. It will not be safe to go deeper because the screw will bend if it be too long. In that case, use intermediate cylinders between the soil and the piston.

The sampler will retain undisturbed the whole layer of soil but the core is somewhat stiffened.

When making this implement, the author used a boiler tube for *a*, but the metal was too soft and the top suffered visible deformation when struck. It was necessary, therefore, to case-harden the metal. Hard steel would be better.

This implement will not be patented.

[1] Acting Director.

THE EFFECT OF DEHYDRATION OF SOILS UPON THEIR COLLOID CONSTITUENTS: II

J. L. STEENKAMP

School of Rural Economy, University of Oxford

Received for publication September 9, 1927

DEHYDRATION EFFECT

Acid-salt-forming bases

When a soil is treated with a weak acid, not only is part of the absorbed bases, calcium, magnesium, potassium, and sodium (i.e. neutral-salt-forming bases), removed, but also a certain amount of iron and aluminum, which Comber (1) has termed the *acid-salt-forming bases* of the soil.

Experiments were conducted to determine the relation between acid-salt-forming and neutral-salt-forming bases, when a soil, at different stages of dryness, is treated throughout with the same concentration of weak acid, and to see whether this relationship will throw any light on the curious effects of the two previously discussed sets of soils (5), when dried out, on neutral-salt-forming bases.

Method. About 20 gm. of soil at each water content were shaken in a mechanical shaker for 3 hours with 200 cc. deci-normal hydrochloric acid, allowed to stand for 24 hours with occasional handshaking, and filtered. Two adequate volumes were then taken from each flask and titrated against standard alkalie, phenolphthalein being used as the indicator for one volume and methyl orange for the other. The difference between the original titer of acid and that obtained when phenolphthalein was used, is the amount of neutral-salt-forming bases, and the difference between the latter and the figure obtained when methyl orange was used is the amount of acid-salt-forming bases. In calculating, the moisture content of soil was taken into consideration each time.

Experimental. A comparison of results obtained for surface and subsoil of the yellow clay-soil (IV), indicates a definite relationship, especially toward closing stages of dehydration between acid-salt-forming and neutral-salt-forming bases as found by extraction with deci-normal hydrochloric acid (table 1). If the graphs obtained for exchangeable bases of these two soils (5, fig. 2) are compared with the figures obtained for acid-salt-forming bases, it is very apparent how, for the surface soil, the big increase in acid-salt-forming bases causes a distinct decrease of exchangeable bases, and the slight increase for the subsoil causes a slight rising in the curve for exchangeable bases. In comparing, at the same time, absorption of calcium bicarbonate for

these two soils (5, fig 5), it is interesting to note that the increase of acid-salt-forming bases definitely causes an increase in the amount of calcium bicarbonate absorbed.

One may safely say, therefore, that the increase of aluminium and iron, when a soil is dried out, is a very important factor in causing an increase in the absorption of bases, and consequently a decrease in exchangeable bases for the same conditions. How far this increase of acid-salt-forming bases is counteracted by the depression of the solubility of iron and aluminium as a result of dehydration, is discussed later (p. 245).

TABLE 1

Effect of dehydration on acid-salt-forming bases and effect of different quantities of soil on (T−S)-estimation at different water contents

SOIL TYPE	ON 100 GM. DRY SOIL, IN MILLIGRAM EQUIVALENTS								
	Water	$T-S$				Lime Requirement	Absorbed Cases		Acid-salt-forming bases $Fe_2O_3 + Al_2O_3$
		2 gm. taken at each water content		5 gm. taken at each water content			Leaching (Hissink)	(Comber) 0.1 N HCl	
	per cent	*per cent* H_2O		*per cent* H_2O					
Yellow clay-soil (No. IV—surface)	39.2	43.3	109.0	39.2	51.0	11.64	42.07	40.10	9.31
	18.2	19.4	95.0	18.2	48.9	9.42	39.12	37.73	14.21
	8.8	9.3	91.0	8.8	49.1	9.56	36.17	32.51	18.13
	0.0	0.0	89.0	0.0	51.9	12.37	32.77	30.40	22.00
Yellow clay-soil (No. V—subsoil)	36.81	71.0	4 gm. soil taken at each water content			8.46	43.20	41.50	8.02
	26.94	59.5				6.08	42.53	40.30	8.83
	14.89	....				5.04	39.70	38.26	9.30
	8.65	57.0				5.50	38.50	37.36	10.02
	0.00	60.5				6.51	38.20	36.81	10.47
Yellow clay (No. V-subsoil	35.95					38.06	After extraction of bases with 0.1N HCl		
	22.64					36.16			
	18.17					34.17			
	6.73					32.78			
	0.00					30.84			

If, therefore, at moist condition of soil, the acid-salt-forming bases, which are soluble in weak hydrochloric acid, are removed and the lime requirement of this base-extracted soil is determined at different stages of dehydration, a steady decrease of the calcium bicarbonate absorption from solution ought to result, as is shown by the other soils with regard to baryta. This was actually the case for the yellow clay-subsoil (5, fig. 5), the graph of which, for absorption of bases, compared very well with those obtained for soils I, II, and III.

It seems appropriate here to compare figures for exchangeable bases for the yellow clay-soil (surface and subsoil, table 1) obtained by the leaching-out

method of Hissink, and by the acid-extraction method of Comber. This soil is deficient in calcium carbonate.

The figures obtained by the deci-normal hydrochloric acid extraction are in both cases slightly lower than those obtained by the leaching-out method, although they both show the same order. Moreover, the same subsoil, from which all the bases have been extracted with the same concentration of acid, also shows figures for base absorptive power slightly less than the amount of bases originally present in the soil. This is, possibly, due to some extent to the initial removal of absorbing material by the acid. Also the deci-normal hydrochloric acid might not have removed all the bases at the initial extraction. In any case, it seems obvious, that in the case of the other two extractions, the acid was slightly too weak for this particular soil.

According to the figures obtained for base absorptive power by Comber (1) for 7 soils, deci-normal hydrochloric acid should be sufficient to extract all the bases from light soils, and fifth-normal hydrochloric acid should be enough for heavy soils. By working with a Clyde clay, Schollenberger (4) found that the base absorptive power increased with the concentration of the acid used up to an acid concentration of about four-tenths normal. With a Miami clay loam, he also found that extraction with deci-normal acid brought the soil to its maximum base absorptive power.

Effect of drying out soils in artificial atmospheres upon neutral-salt-forming and acid-salt-forming bases

Now that it has been established that the reason for the abnormal behavior of the yellow clay-soil is the formation of fresh absorbent, the question still arises whether the removal of water alone, or in combination with other factors, is the cause of the creation of this new absorbing material; and to what extent, after a certain length of time, will the absorptive capacity become depressed, as a result of dehydration.

To throw some light on these points it was decided to dry out different soils in artificial atmospheres of varying natures, over concentrated sulfuric acid, and then in each case to estimate the amount of neutral-salt-forming bases as well as acid-salt-forming bases.

Method. Certain quantities of moist soil were well spread out on saucers, which were placed inside desiccators containing concentrated sulfuric acid. The required gases were first passed through sulfuric acid to remove all traces of moisture, and then sent through the desiccators containing the soil. When all the air had been displaced, the desiccators were closed, and left to stand for about 14 days, with occasional additions of gas until a constant weight for the dry soil was obtained. From the acid extracts of the dry soil thus obtained, the determinations for acid- and neutral-salt-forming bases were made. The strength of the hydrochloric acid solution used for the extraction of the bases from clay-soil (IV) was fifth-normal, and for both soils I and II it was deci-normal.

Effect of different gases. Adequate quantities of yellow clay-soil (IV), black loam (II), and sandy humus (I) were each treated as described, with carbon dioxide, oxygen, nitrogen, and air. The sandy humus-soil contained calcium carbonate.

The results thus obtained (table 2) corroborate those obtained from leaching experiments (Hissink), assuming that the calcium carbonate in soil I is uniformly distributed. Uneven distribution, however, would not interfere with the estimation of acid-salt-forming bases by this method. The neutral-salt-forming bases of soils IV and II both being deficient in calcium carbonate, are comparable with results obtained by Hissink's method of leaching or exchanging the bases with normal solutions of sodium chloride and ammonium chloride. The presence or absence of calcium carbonate would make no difference in comparing the acid-salt-forming bases of the three soils.

TABLE 2

Effect of drying soil in artificial atmospheres upon neutral-salt-forming and acid-salt-forming bases

METHOD OF DRYING SOIL	ON 100 GM. DRY SOIL IN MGM. EQUIVALENTS					
	IV. Yellow clay-surface		II. Black clay (light)		I. Sandy humus	
	Neutral-salt-forming bases	Acid-salt-forming bases	Neutral-salt-forming bases	Acid-salt-forming bases	Neutral-salt-forming bases	Acid-salt-forming bases
Dehydration over concentrated H_2SO_4 in atmosphere of CO_2 (*A*)	40.85	25.89	41.68	12.73	23.46	7.99
Dehydration over concentrated H_2SO_4 in atmosphere of oxygen (*B*)	42.64	23.55	43.17	12.48	22.96	7.74
Dehydration over concentrated H_2SO_4 in atmosphere of air (*C*)	42.41	24.56	42.68	12.48	23.21	7.99
Dehydration over concentrated H_2SO_4 in atmosphere of nitrogen (*D*)	43.20	22.01	39.68	11.98	23.21	7.74
Dehydrated in atmosphere of nitrogen and then left in oven for 24 hours at 100°C	42.64	26.12	40.18	13.48	23.24	7.99
Dehydrated in atmosphere of nitrogen and then left in oven for 6 days at 100°C	42.54*	28.01	38.34	14.71	22.21	7.74
Fresh soil left in oven for 24 hours at 100°C	39.29	27.82	41.93	12.01	24.21	6.49
Moist soil	49.84	15.91	37.02	13.44	22.61	7.74

* 5 days.

Soil dried over concentrated sulfuric acid in an atmosphere of nitrogen would seem a very effective control, since the only factor that comes into play here is apparently dehydration, and would therefore, do well for comparison not only with moist soil but also with soil dehydrated in artificial atmospheres other than nitrogen.

After the change from moist to dry condition, the yellow clay-soil (IV)

shows a definite decrease in neutral- and a definite increase in acid-salt-forming bases, whereas the reverse is the case with the light clay-soil (II) and sandy humus-soil (I). With the sandy humus-soil, however, the change is not so striking. Again it is apparent that the effect on bases is determined by either increase or decrease of acid-salt-forming bases, as has been previously discussed (p. 242). These figures account admirably for the decrease of the neutral-salt-forming bases which were obtained from yellow clay-soil, and for the increase of the same for sandy clay and sandy humus by Hissink's method of exchanging the bases.

A comparison of figures obtained from yellow clay-soil dried out in artificial atmospheres indicates that an atmosphere of carbon dioxide gives the highest figure for acid-salt-forming bases and a correspondingly low figure for neutral-salt-forming bases. This fact is, possibly, due to carbonic acid reaction on the partly undecomposed soil particles of aluminum and especially iron silicates, and on the Van Bemmelen's colloidal complex of aluminum and iron hydroxides with humus. The acid-salt-forming base content is lowest in soils dried out in a nitrogen atmosphere, slightly higher in an oxygen atmosphere, and higher still in an atmosphere of air, so that the effect of oxidation, although considerable, is less than that of carbon dioxide. Neither does the effect of a mixture of oxygen and carbon dioxide, as it exists in air, exceed that of carbon dioxide alone.

For soils I and II the carbon dioxide action is also greater than that of any other gas, although there is a decreasing effect of decomposition from soil IV to II and I; namely, 3.88, 0.75, and 0.25 mgm. equivalents. This is because soil IV contains far more iron and aluminum compounds than either II or I and would naturally give a greater amount of aluminum and iron through the action of carbonic acid. The different effects of oxygen and air on soils II and I are less striking and are probably due to the aluminum and iron compounds which occur in initially smaller amounts, and are also more decomposed than in IV, which gives a figure of 3.88 mgm. equivalents as compared to 0.75 and 0.25 of II and I, respectively.

Effects of dehydration, carbon dioxide, and heat on neutral- and acid-salt-forming bases

The results obtained with soil which has been dehydrated without the application of heat (dehydration in atmosphere of nitrogen over concentrated sulfuric acid), and subsequently treated at 100°C. for different periods in a steam oven, confine separately the effect of heat and dehydration upon the soil constituents. The effect of carbonic acid alone, without the process of dehydration, was also determined, and discussed on page 246.

Effect of heat. It appears that when heat alone is applied, considerably more acid-salt-forming bases go into solution after 24 hours than after periods of 5 or 6 days. In fact with soil I, after 6 days heating, the amount of acid-salt-forming bases is lowered to its original amount. The extent of this depression,

possibly, depends on the amount of decomposable material present in the soil. Depression and creation of fresh absorbent occur simultaneously, the former very much slower than the latter, so that the depression effect is only noticeable after the decomposition ceases (5, fig. 4). The solubility of the acid-salt-forming bases in soil I, which has considerably less material for decomposition than soil IV, would be more readily decreased than soil IV which with decrease of solubility is capable of creating more acid-salt-forming bases; this latter effect would overshadow the former.

It is important to note that the amount of neutral-salt-forming bases going into solution is dependent on the magnitude of the depression of the acid-salt-forming bases. In soils containing humus the amount of neutral-salt-forming bases going into solution is still further increased by the rapid loss of the colloidal state of the humus.

Effect of dehydration. The result of dehydration alone agrees with this argument, since soil IV gives an increase of 6.10 mgm. equivalents acid-salt-forming bases, soil II gives a decrease of 1.46, and soil I shows no change (table 2).

Effect of heat and dehydration. There is a distinct difference with regard to neutral-salt-forming, and acid-salt-forming bases between a soil that has been first dehydrated in an atmosphere of nitrogen without application of heat and then treated in an oven for 24 hours at 100°C., and a fresh soil that has undergone the same oven treatment for the same time and at the same temperature without being initially dehydrated. Dehydration increases the neutral-salt-forming bases going into solution in soils II and I which contain fewer iron and aluminum compounds than soil IV. In these two soils depression would therefore set in sooner than in soil IV, with the result that in them more exchangeable bases would be available and correspondingly less soluble iron and aluminum. Soil IV may, if heating is continued for a longer period, be benefitted in the same way, because of larger iron and aluminum content.

It would appear from figures quoted that the temperature of dehydration may be the cause of this phenomenon. The presence of water, when the temperature is raised, will facilitate the process of hydrolysis, so that a quicker depression will set in, where the available amount of decomposable material is small. This increased depression, however, would be slightly counteracted by the combined decomposition effect of dehydration alone and applied heat, because of the quicker escape of water vapor.

Relative intensity of carbonic acid, loss of water, and heat effects. These experiments were conducted to determine the effect of carbonic acid alone as compared with the effects of heat and dehydration, separately or together, on neutral- and acid-salt-forming bases of yellow surface clay-soil (IV).

To estimate the effect of carbonic acid, without dehydrating the soil at the same time, an experiment nearly similar to those done for drying out soil in artificial atmospheres was conducted. To keep the soil at a more or less constant moisture content, moist carbon dioxide was passed into a desiccator, where the sulfuric acid had been replaced by a small quantity of water. The

soil was left for periods of 8 to 26 days, and each time analysed for neutral-salt-forming and acid-salt-forming bases. The moisture content was comparatively slightly affected during these periods.

If we consider separately each of the aforementioned factors, it appears (table 3) that dehydration gives the highest figure for solubility of iron and aluminum in weak hydrochloric acid solution. Dehydration over concentrated sulfuric acid gives 6.10 mgm. equivalents acid-salt-forming bases (difference between 3 and 1), carbonic acid reaction 0.55 mgm. equivalents for 8 days and 1.94 for 26 days; heating at 100°C. for 24 hours, 4.01 mgm equivalents and for 5 days 6.00 (difference between 4 and 3, and 5 and 3). Dehydration, over concentrated sulfuric acid and in an atmosphere of nitrogen, of a

TABLE 3

Comparison of effects of carbon dioxide and dehydration and heat on neutral-salt-forming and acid-salt-forming bases of yellow surface clay-soil

TREATMENT OF SOIL	WATER CONTENT AFTER TREATMENT	ON 100 GM. DRY SOIL	
		Neutral-salt-forming bases	Acid-salt-forming bases
Effect of carbon dioxide			
	per cent	*mgm. equiv.*	*mgm. equiv.*
Untreated moist soil	42.83	49.80	15.6
Above soil left in desiccator in atmosphere of CO_2 for 8 days	41.63	47.83	16.15
Same treatment as above for 26 days	41.95	42.91	17.54
Effect of dehydration and heat			
1. Untreated moist soil	40.94	49.84	15.91
2. Fresh moist soil dried out in atmosphere of air over concentrated H_2SO_4	.....	42.41	24.56
3. Dehydration in atmosphere of nitrogen over concentrated H_2SO_4	.....	43.20	22.01
4. Dehydration in atmosphere of nitrogen and then left in oven for 24 hours 100°C	.....	42.64	26.12
5. Dehydration in atmospheres of nitrogen and then left in oven for 118 hours	.....	42.54	28.01

soil on which the effect of heat was then determined, might hamper the heating effect a good deal, so that material which heating might have decomposed has already been changed by dehydration.

Under field conditions it is not to be expected that the effect of dehydration, carbon dioxide, and heat, will be so intense as in these experiments, except perhaps the effect of dehydration. From this it would be expected that the process of dehydration would give the lowest figure for neutral-salt-forming bases for yellow clay-soil (IV). In soils III and I, because of a smaller amount of decomposable material, the acid-salt-forming bases would decrease with a consequent rise in the neutral-salt-forming bases.

Now that we know to some extent the cause of the creation of new absorbing material, a further question still arises as to the nature of the resultant increased absorptive power. Is it a chemical or a physical phenomenon, or possibly both?

Comber (1) contends that, if it is true that the aggregation of soil particles is brought about and maintained by the binding or cementing action of gel material, then the first effects of heating a soil will be dehydration, shrinkage, and cracking of the gel. This will presumably cause a loosening of the aggregate and consequent increase in the exposed surface. This new exposed surface will in part account for the increase in solubility of the iron and aluminum, and also for the increase in soluble matter, when a soil is dried out.

The mechanical analysis (5, table 1) shows how the cementing action increases according to dryness for the clay-soil (II), where no chemicals whatever were used for the analysis. This certainly points to a further cementing action rather than to a loosening of the aggregates as the soil loses its moisture.

If the cracking of the gel material, with a consequent increased exposed surface, be true, then, if no other factors come into play, the effect on the neutral- and acid-salt-forming bases of drying out soil in artificial atmospheres, ought to be the same. This, however, is not the case. The same fact is shown by figures obtained for soil left in a carbon dioxide atmosphere for different periods without dehydration, where obviously no cracking of gel material could take place.

The difficulty in determining which of these two factors, namely, new exposed surface or decomposition, will have the greater effect on the soil, is intensified by the complexity of the emulsoid surface of the particles. From previous figures it is clear that the greatest changes in neutral- and acid-salt-forming bases, are effected by loss of water, heat, and a combination of these two. Whether the newly exposed surface of the soil particles dominates the decomposition is an open question, although the decomposing effect seems more probable.

Absorption-coefficient at different degrees by dryness for deci-normal solutions of the more important plant nutritive substances

The different salts used for this purpose were disodium hydrogen phosphate, potassium nitrate, calcium nitrate, and ammonium chloride. The absorption of ammonium chloride was more thoroughly investigated, being ultimately correlated with the amount of absorbed bases (S) held by the soil.

About 50 gm. of previously prepared soil at each water content were shaken for 3 hours in a mechanical shaker with 200 cc. of either hundredth- or tenth-normal solutions of the required salt and left to stand for 48 hours with occasional hand-shaking (3). For estimation of salt 20 or 25 cc. of the original solution were then taken and compared with the solution containing the soil, the difference being the amount of salt absorbed by the soil. The absorption coefficient (2) is the amount of absorbed material in milligrams reckoned on

100 gm. of soil; in this case it was reckoned on dry soil. On drying out, the light black clay no. II shows an increase and the yellow clay no. V shows a decrease in both the absorption-coefficient for hundredth-nominal solution of disodium phosphate, and the exchangeable bases. Apparently this is due to the precipitation action of calcium on the phosphate solution (table 4).

For deci-normal potassium nitrate and deci-normal calcium nitrate the

TABLE 4

Absorption of salts at different water contents

SOIL TYPE	SALT USED	WATER	ABSORBED BY 100 GM. DRY SOIL	
		per cent	*mgm.*	*mgm. equiv.*
		P_2O_5		
Light Black Clay (No. 11)	0.01*N* Na_2HPO_4	34.12	46.17	1.62
		24.39	47.21	1.66
		16.03	48.94	1.72
		7.09	49.66	1.75
		0.00	50.10	1.76
Yellow Clay Subsoil (No. V)	0.01*N* Na_2HPO_4	36.81	106.00	3.73
		26.94	98.20	3.44
		14.89	95.90	3.38
		8.65	95.60	3.36
		0.00	94.90	3.34
		K_2O		
Yellow Clay Subsoil (No. V)	0.1 *N* KNO_3	37.94	930.90	19.76
		29.09	879.80	18.68
		16.53	868.00	18.43
		12.30	858.00	18.22
		0.00	816.75	17.34
		CaO		
Yellow Clay Subsoil (No. V)	0.1 *N* $Ca(NO_3)_2$	36.81	484.20	17.27
		26.94	201.60	7.19
		14.89	136.80	4.88
		8.65	65.13	2.32
		0.00	63.25	2.26

yellow clay-soil gives a decrease in the absorption coefficient which is very much more pronounced in the latter case than in the former. This is apparently because calcium predominates over the bases in exchangeable form.

Correlation of absorbed bases (S) and absorption of deci-normal ammonium chloride

The absorption of deci-normal ammonium chloride solution for four different soils, at different water contents, has been determined (p. 248) and compared to the amount of exchangeable bases held by the same soils (table 5).

From graphs obtained for absorption of deci-normal ammonium chloride (figs. 1 and 2), it is very clear that the absorption decreases for all soils according to degree of dryness. This absorption decreases, however, very much more in the case of the two pasture soils (V and IIIb) both of which also give a decrease in exchangeable bases as the soil is dried out.

The difference between the amount of absorption of a deci-normal ammonium chloride solution, and the amount of absorbed bases in the soil, both in milligram equivalents on 100 gm. dry soil, would obviously give, for this strength of ammonium chloride solution, either the amount of available bases or the amount of base the soil could still absorb, according to whether S is higher or lower than the amount of ammonium chloride at any particular moisture content. This optimum moisture content is clearly shown (figs. 1

TABLE 5

Correlation of absorbed bases (S) and absorption of deci-normal solution of ammonium chloride at different water contents

SOIL TYPE	WATER	ON 100 GM. DRY SOIL: N absorbed	ON 100 GM. DRY SOIL: $(NH_4)_2O$ absorbed	ON 100 GM. DRY SOIL: Absorption of 0.1 N NH_4Cl	ON 100 GM. DRY SOIL: Total absorbed bases (S) originally in soil	$S - 0.1\ N\ NH_4Cl$	
	per cent	*mgm.*	*mgm.*	*mgm. equiv.*	*mgm. equiv.*		*mgm. equiv.*
Sandy humus (No. I)	24.59	176.9	321.4	12.34	18.75	Available bases	6.41
	13.41	150.4	279.7	10.74	21.70	Available bases	10.96
	6.0	143.5	266.9	10.25	23.40	Available bases	13.15
	0.0	140.4	261.0	10.02	24.90	Available bases	14.88
Light black clay (No. II)	34.12	344.5	640.6	29.50	19.75	Still absorbs	9.75
	24.39	290.7	540.5	23.30	23.25	Still absorbs	0.05
	16.03	252.2	468.8	18.05	27.19	Available bases	9.14
	7.09	218.9	406.8	15.68	32.65	Available bases	16.97
	0.00	191.8	356.6	13.69	36.00	Available bases	22.31
Yellow Subsoil (No. V)	37.94	720.9	1340.0	51.45	43.26	Still absorbs	8.19
	29.09	598.9	1114.0	42.75	42.60	Still absorbs	0.15
	16.53	456.6	848.9	32.60	41.20	Available bases	8.60
	7.54	376.0	699.0	26.84	39.25	Available bases	12.41
	0.00	325.7	605.4	23.25	38.25	Available bases	15.00
Fairly heavy clay (subsoil No. IIIb uncultivated)	23.33	308.2	572.9	22.00	27.02	Available bases	5.02
	21.04	271.7	505.3	19.40	26.75	Available bases	7.35
	18.96	248.6	462.3	17.75	26.24	Available bases	8.49
	14.09	198.6	369.3	14.18	25.40	Available bases	11.22
	9.80	161.1	299.5	11.50	23.63	Available bases	8.49
	6.90	136.6	253.9	9.75	22.31	Available bases	11.22
	5.41	47.97	217.5	8.35	21.43	Available bases	13.08
	0.00	7.02	130.5	5.01	17.48	Available bases	12.47

and 2) when the amount of exchangeable bases and the amount of absorption of deci-normal ammonium chloride are separately graphed against moisture content on the same scale.

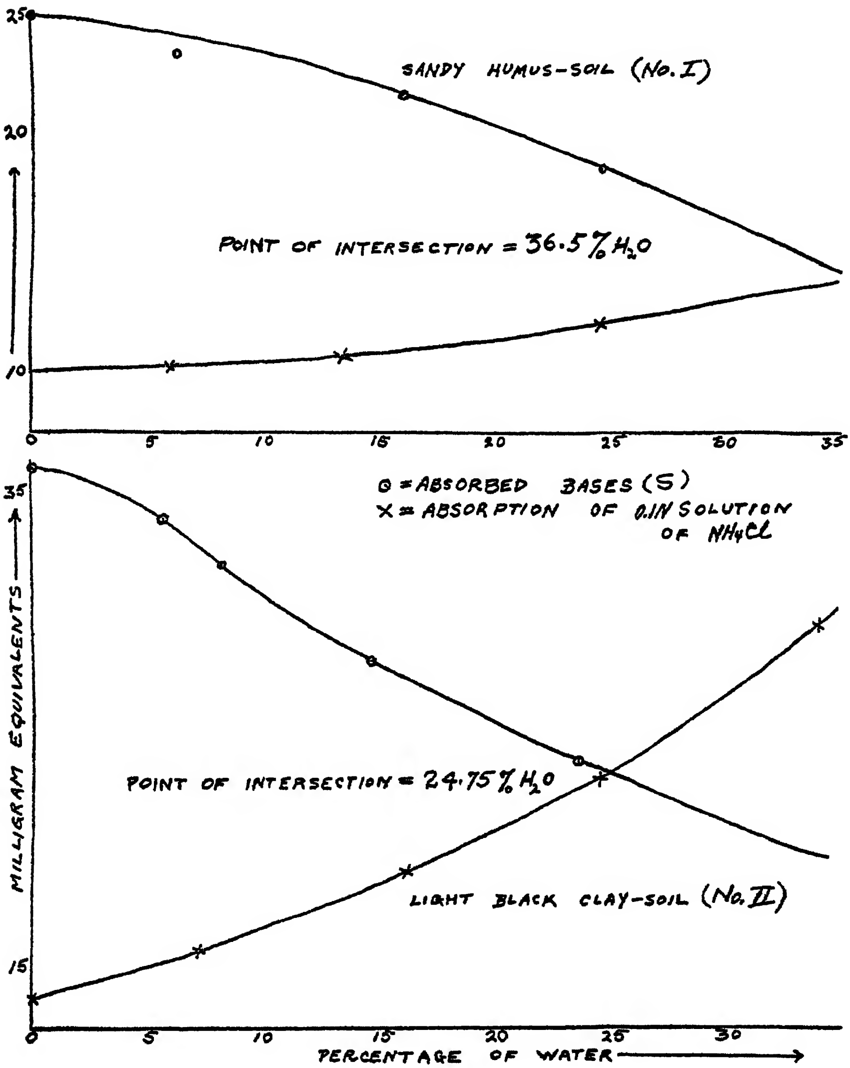


Fig. 1. Correlation of Absorbed Bases (S) and Absorption of Deci-normal Solution of Ammonium Chloride

When the soil is dried out the greatest amount of available bases is shown by the light black clay-soil (II). The difference between this soil and the next

highest (yellow clay-subsoil), which is more or less the same as the sandy humus, is 7.31 mgm. equivalents, whereas the uncultivated clay-subsoil (IIIb) is the lowest, possibly because of its unweathered condition.

The optimum moisture-content differs considerably for the four soils experimented upon (figs. 1 and 2). The sandy humus (I) gives the point of intersection as 36.5 per cent water, the highest of the four soils. This soil would ordinarily never reach that water content, so that drying out would invariably give available bases. The black clay-soil, on the other hand, has a point of intersection of 24.75 per cent water, which is the lowest figure, so that absorp-

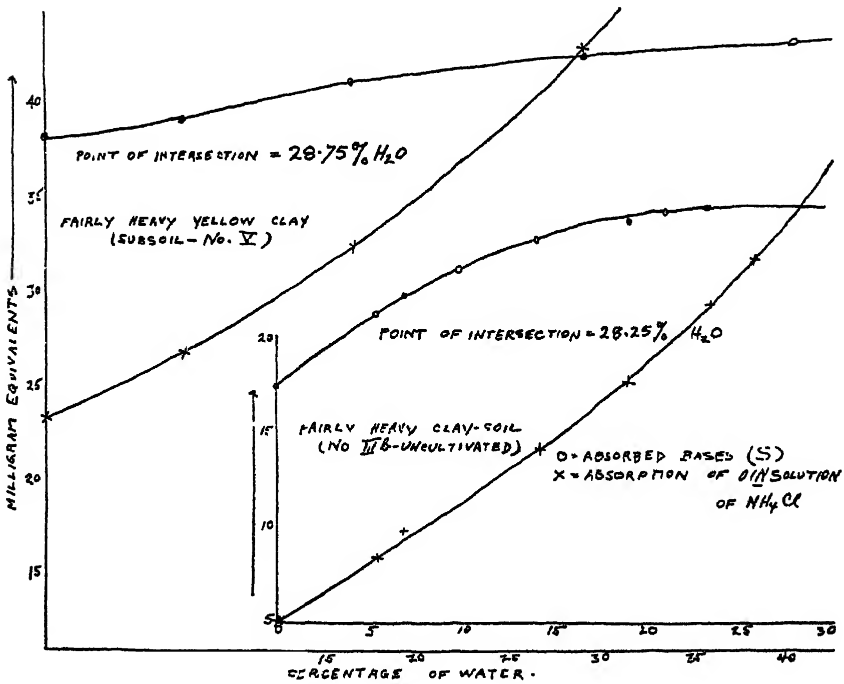


FIG. 2. CORRELATION OF ABSORBED BASES (S) AND ABSORPTION OF DECI-NORMAL SOLUTION OF AMMONIUM CHLORIDE

tion of ammonium chloride here continues, when the soil is dried out, until this water content is reached. From this point, bases would then become available. The two pasture soils, yellow clay (V) and clay-soil (IIIb), have points of intersection of 28.75 per cent and 28.25 per cent water, respectively.

Previous experiments indicate how drying out of soils V and IIIb creates more absorbing material, whereas the absorption of bases definitely decreases for the black clay-soil (II). Despite this fact, it is found that in soil II the absorption of the deci-normal solution of ammonium chloride diminishes to a much lower percentage of water for the point of intersection of the two curves.

The behavior of soils V and IIIb is, in a similar way, unexpected. This might possibly be explained in the following manner. The ammonium chloride not only exchanges the bases, but also some of the hydrogen ions, the substitution of which proceeds more slowly than in the former process. In the case of the black clay-soil (II) there is an increasing quantity of bases and an increasing saturation with dehydration, whereas for the other two soils, exactly the opposite is true, so that because of the slowness of the hydrogen-ion exchanged, these latter two soils would loose their absorptive power for ammonium very much sooner than the black clay-soil.

Similarly for the sandy humus-soil (I), exchange of the bases as well as the hydrogen ions will take place. But it will be remembered from previous discussions that the sandy humus loses its base-absorptive power very readily on being dried out, so that absorption of ammonium, as measured by the exchange of hydrogen ions, is small. The destruction of the absorptive power by dehydration will also affect the bases. Part of the total bases (*S*) will go into solution, as a result of this destruction, rather than as a result of exchange, so that again absorption of ammonium will be decreased.

The combined result of hydrogen-ion and base exchange, when such a soil is treated with ammonium chloride solution, will lower the absorption of ammonium considerably. In correlating the absorption of ammonium and the total base content of the soil, the optimum moisture content for the sandy humus will obviously be considerably higher than that of any of the other three soils.

From a consideration of the curves for absorbed bases and absorption of ammonium (figs. 1 and 2) and their points of intersection, it would appear that if the points of intersection be regarded as indicating a water content below which soluble material is set free, the beneficial effects of dehydration in increasing the supply of plant nutrients, particularly calcium, will commence earlier (when the soil contains a higher water content—as in soils I, V, and IIIb) than in soil II. This latter soil shows the greatest amount of available bases on drying out.

REFERENCES

(1) Comber, N. M. 1922 The flocculation of soils: III. *Jour. Agr. Sci.*, 12: 374.

(2) Fesca, M. 1882 Beitrage zur Agronomischen Bodenuntersuchung. Berlin.

(3) König, J. 1923 Untersuchung landwirtschaftlich und landwirtschaftlich-gewerblich wichtiger Stoffe, ed. 5, v. 1: 106.

(4) Schollenberger, C. J. 1917 Relation between indications of several lime-requirement methods and the soils content of bases. *Soil. Sci.*, 3: 279–288.

(5) Steenkamp, J. L. 1928 Effect of dehydration of soils upon their colloid constituents: I. *Soil Sci.*, 25: 163–182.

A LABORATORY APPARATUS FOR THE MEASUREMENT OF CARBON DIOXIDE EVOLVED FROM SOILS

FRANKLIN W. MARSH

Bureau of Plant Industry, U. S. Department of Agriculture

Received for publication November 9, 1927

INTRODUCTION

For determining, in the laboratory, the amounts of carbon dioxide evolved from soils, an apparatus was desired which would be simple of operation, compact in arrangement, and by means of which the carbon dioxide could be determined by the absorption method found most desirable. An apparatus was, therefore, assembled which met these requirements and which was made up from readily obtainable material.

This apparatus is simple of operation and very compact, 20 units (sufficient for making duplicate determinations on 9 soils and maintaining 2 controls) occupying a bench space of only 3 by 7 feet. This space accommodates not only the units themselves but also a thermograph, a filling apparatus, a 10-liter potassium hydroxide solution reservoir, a 2½-liter distilled water container, a meter, a scrubbing system, and suction flasks. Determinations may be made by any of the usual absorption methods, liquid absorbents and either the absorption device to be described or any similar device, being used.

Previous tests on Ascarite (3) and on soda lime indicated the superiority of liquid absorbents for work on moist soils but if special requirements make the use of solids more desirable, they may, of course, be used with this apparatus when the absorbents are properly protected by driers and suitable absorption devices are used.

DESCRIPTION OF APPARATUS

The complete apparatus is shown in plate 1 and its construction and arrangement are detailed diagrammatically in figures 1 and 2.

The air is drawn through the apparatus by means of a water aspirator, and three filtering flasks *A*, *B*, and *C* (fig. 1) are maintained between this and the apparatus. Flask *A* contains water and indicates the rate of air flow, *B* is a safety flask to protect the apparatus, and *C* acts as a distributor, 10 lines leading from it, each line connecting with 2 units.

Each unit consists of a 1-liter filtering flask (*D*, fig. 2) and a ½-gallon glass percolator (*E*) with a glass tube ⅛ inch in diameter and 4 inches long attached to the bottom outlet with a rubber stopper. The percolator and flask are

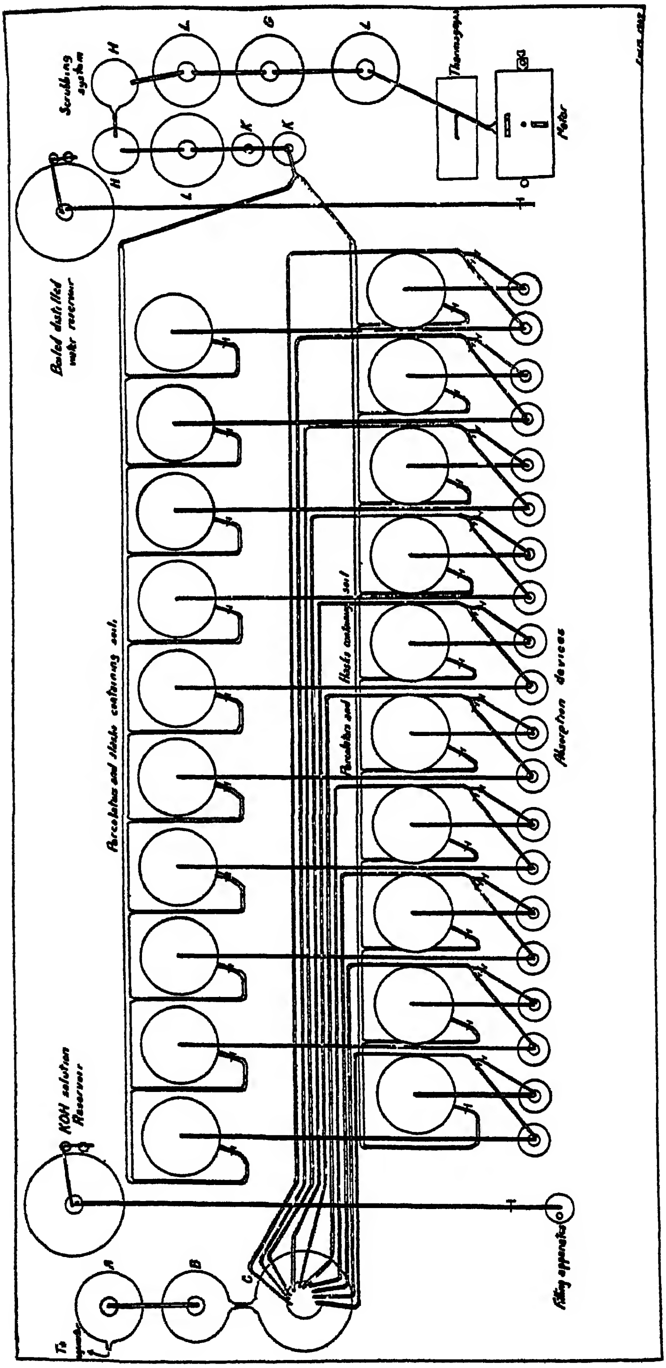


FIG. 1. DIAGRAM OF ARRANGEMENT OF APPARATUS

joined by means of a rubber stopper and the two are supported on a ring support and ring. Both the percolator and the flask are used as soil containers. A funnel (*F*), approximately the same diameter as the top of the percolator is affixed to it (after the charge of soil is in place) in the following way: Adhesive plaster, ¾ inch wide, is wrapped around the edge of the funnel and the

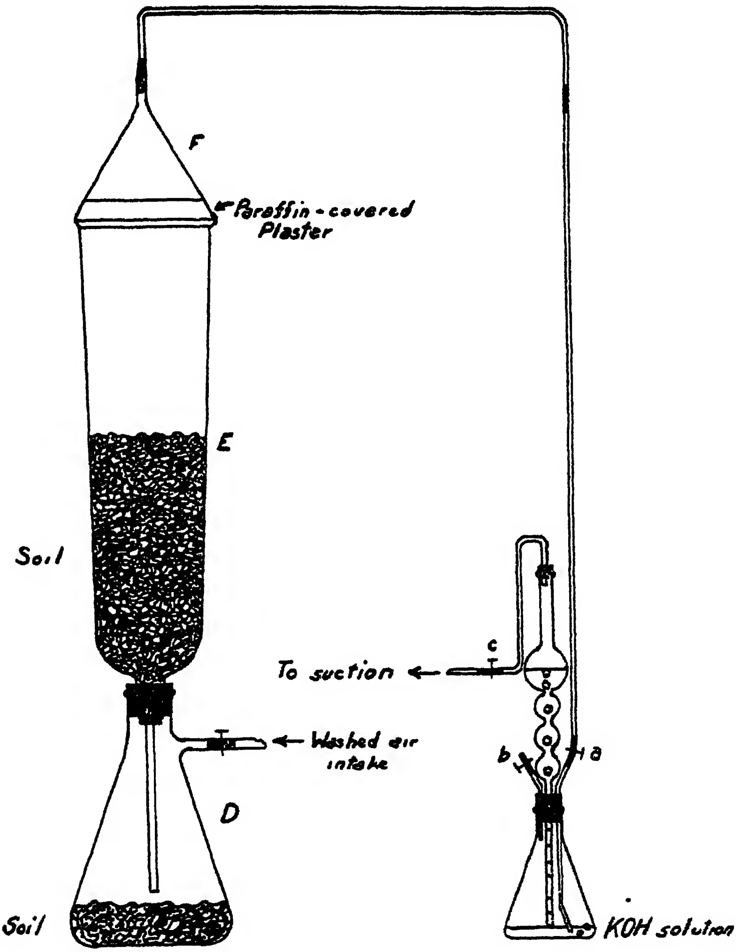


FIG. 2. DIAGRAM OF A UNIT

percolator where they come together, and is carefully coated with paraffin with a melting point of 55°C. Two other pieces of plaster are then wrapped around this so as to overlap its edges, and are covered with a heavy coating of paraffin. This method of sealing has proved very reliable and no evidence of leakage has been detected.

In this multiple set-up any leak interferes with the bubbling in the absorption devices or with the running of the meter and, although the apparatus over the period of a year's service has developed very few leaks, it is important, when these are present, that they can be readily detected. The use of high-quality rubber tubing and stoppers, frequently renewed, is advisable. A glass tube connects the stem of the funnel with the absorption device, which consists of a 200 cc. Erlenmeyer flask with a rubber stopper carrying a series of bulbs and two tubes (fig. 2). This device is efficient, as shown by tests for complete absorption of carbon dioxide. The tubulatures from the filtering flasks (*D*) are connected to manifolds (made of glass tubing) which lead to the scrubbers. The latter consist of a flask containing concentrated potassium hydroxide solution (*G*, fig. 1), one or more towers filled with soda lime (*H*), two flasks containing barium hydroxide solution (*K*) to humidify the washed air and to indicate the efficiency of the scrubbers, and guard flasks (*L*).

The air-measuring instrument is a Wet Test Meter and is very accurate and dependable in its operation. This is connected with the intake of the scrubbers and measures all the air going through the apparatus. The filling apparatus used with the potassium hydroxide solution consists of a separatory funnel, marked to deliver approximately 65 cc., and connected to the potassium hydroxide reservoir. For use with barium hydroxide solution as an absorbent, the separatory funnel may be replaced by a burette or pipette to increase the accuracy of the measurements. The potassium hydroxide solution is, at all times, protected from carbon dioxide contamination by means of guard tubes on the potassium hydroxide solution reservoir and on the filling apparatus.

OPERATION OF APPARATUS

First, 1,000 gm. of the soil to be tested, which has been screened through a no. 5 U. S. Standard sieve and thoroughly mixed, is placed in a percolator, a glass wool plug preventing leakage through the bottom outlet. Five hundred grams from the same sample of soil is placed in a filtering flask and the apparatus then assembled as described. The absorption devices are charged with 0.25 *N* potassium hydroxide solution,[1] by means of the filling apparatus, in the following manner. Tube *b* (fig. 2) of a device is attached to a manifold outlet, all other outlets in the manifolds being closed. Tube *a* is attached to the outlet of the separatory funnel, and tube *c* to a suction line. The clamp on tube *a* is closed and the clamps on the other two tubes are opened. The device is then thoroughly flushed by drawing carbon doxide-free air from the scrubbers through it while 65 cc. of potassium hydroxide solution is being drawn from the storage bottle into the separatory funnel. The clamp on tube *b* is closed and that on *a* and the stopcock on the separatory funnel are opened and the potassium hydroxide solution is drawn into the 200-cc. flask.

[1] Potassium hydroxide solution is used because of its efficiency as a carbon dioxide absorbent as demonstrated by Ledig (2). The 0.25*N* dilution was found to be very convenient.

The clamps on tubes *a* and *c* and the funnel stopcock are closed, the three tubes detached, and *a* is attached to a percolator outlet and *c* to one of the suction lines. The bulb tube is adjusted so that when suction is applied, the potassium hydroxide solution will fill the three lower bulbs and about half fill the top one.

After the absorption devices are all in place, the clamp on the manifold outlets used with the filling apparatus is closed and all the others are opened. The clamps on tubes *a* are opened wide and those on tubes *c* adjusted so that washed air passes through each unit at the desired rate. About 800 cc. of air per hour gave satisfactory results with the soils tested. The first run of the apparatus is from 12 to 24 hours to flush from the soil all accumulated carbon dioxide. After this the absorption units are washed out, refilled with potassium hydroxide solution, and connected as before. The apparatus is then run for periods of from 72 to 96 hours, these having been found by preliminary experiments to be the optimum time limits for each determination for the soils used. A shorter time often gave an amount of gas too small for dependable comparison, whereas a longer period was found undesirable as too much time elapsed between determinations so that changes in amounts of gas evolved were not readily followed.

After a run is completed the absorption devices are disconnected, after all clamps have been closed, and a tube containing soda lime is attached to tube *c* on each device in turn and the clamp at this point opened. Clamps on tubes *b* and *a* are then opened in the order named. The stoppers carrying the absorption bulbs and tubes *b* and *a* are loosened and all potassium hydroxide solution is washed from each set of these bulbs and tubes with 25 cc. of boiled, distilled water drawn from the water reservoir which is protected from carbon dioxide by guard tubes. The potassium hydroxide solution in the flask is titrated to determine the amount of carbon dioxide absorbed.

Although any reliable method of titration may be employed the one described by Simpson (5) has been used with some modifications and gives satisfactory results. Ten drops of an indicator consisting of 6 parts of thymol blue, and 1 part of cresol red solution is added and approximately 0.25 N hydrochloric acid solution run in until the pink color disappears, the solution in the flask being kept in motion during this addition to prevent a local excess of acid. Eight drops of brom phenol blue indicator is now added and approximately 0.1 N hydrochloric acid solution, of which the normality factor is known, added until the pink again disappears. All titrations are made by means of transmitted light from a properly shielded electric light bulb. The indicator solutions are made in accordance with the specifications of Clark (1). This method of titration gives easily detected end-points, and the results of tests with pure sodium carbonate indicate that it is sufficiently accurate.

Data obtained, by means of this apparatus, from 7 samples of soil which were run in duplicate over a total period of 28 days are given in table 1. The titration figures for each determination on the soils have been converted to milli-

TABLE 1

Milligrams of carbon dioxide evolved from soils during 72-hour periods

DETERMINATION NUMBER	HOURS RUN	CONTROLS		BEET SOIL		CORN SOIL		WHEAT SOIL		COWPEA SOIL		GRASS I-II SOIL		SOYBEAN SOIL		GRASS I SOIL	
1	72	9.2	16.3	44.2	49.9	109.1	128.0	162.4	170.1	72.5	61.2	128.2	105.1	56.9	51.7	61.7	74.1
2	72	8.5	10.7	40.9	45.5	100.6	119.7	140.1	137.6	64.8	63.2	112.5	88.5	44.3	47.6	54.6	63.3
3	72	7.6	10.0	31.6	31.6	72.7	95.5	102.0	104.5	46.8	43.0	79.9	68.7	34.8	36.3	39.9	47.1
4	72	8.2	8.7	34.4	35.6	88.5	94.2	119.1	110.7	48.3	41.6	86.7	69.6	37.1	34.4	40.8	48.3
5	96*	8.2	9.3	29.3	30.4	85.1	77.2	103.7	97.4	45.0	45.2	80.6	65.3	31.8	30.9	36.4	43.5
6	72	8.8	9.4	29.5	36.0	69.5	67.4	102.4	102.3	42.6	39.8	74.4	....	33.9	32.8	33.9	40.6
7	96*	8.4	10.2	23.7	26.3	....	52.5	78.5	74.9	37.3	31.1	62.3	51.1	....	31.6	30.8	32.9
8	72	8.3	8.8	....	26.0	53.1	53.6	87.4	83.0	34.7	36.3	....	51.6	29.5	32.8	31.3	32.7

* Figures are calculated to a 72-hour basis.

grams of carbon dioxide evolved during 72-hour periods. Those for the controls have been treated in a similar way except that, as they represent to a large extent the carbon dioxide present in the potassium hydroxide solution at the beginning of the determinations, no adjustments for length of run have been made.

DISCUSSION

The apparatus described is well suited for the determination of carbon dioxide evolved from soils under laboratory conditions inasmuch as the space occupied is relatively small, its operation is not difficult, the chance of error due to leakage is slight, and results are satisfactory. Various methods of carbon dioxide measurement using different types of absorption devices and absorbents (the filling apparatus being modified when necessary), thus satisfying personal preference or fulfilling special experimental requirements, may be used with this apparatus and the accuracy of the results may be increased to the desired degree. The number of units in the apparatus may, of course, be varied from the 20 in the set-up described in this paper.

In this laboratory, soil is always placed in both the flask and the percolator so as to combine, at least to some extent, the two methods previously used; namely, the passage of carbon dioxide-free air through the soil to remove the carbon dioxide evolved, and the drawing of such air over the soil for the same purpose. Potter and Snyder (5) have pointed out that the passage of carbon dioxide-free air through soil may cause an error due to the effect on the bacteria of the abnormal atmosphere produced. The method described in the present paper should largely eliminate the error due to this cause as the washed air is first passed over the soil in the flasks and so does not produce a carbon dioxide-free atmosphere around the bacteria when passed through the soil in the percolators. On the other hand, the advantage of an aeration more nearly resembling that in the field is obtained by the passage of the air through the soil[2] as well as over it.

Of course the soil in the flask can be omitted, in which case water may be placed therein to aid, in the case of soils with high moisture contents, in the maintenance of as nearly as possible the same moisture conditions in the soil throughout the experiment.

SUMMARY

1. A complete apparatus for the measurement of carbon dioxide evolved from soils under laboratory conditions is described.
2. The method of operation of the apparatus is given.

[2] A test of carbon dioxide evolution from soil contained in the flasks only and over which carbon dioxide-free air was passed, and in the percolators only and through which similar air was drawn, showed that the evolution of carbon dioxide was about 14 per cent higher for the soil tested, with carbon dioxide-free air passed through it than with such air drawn over it.

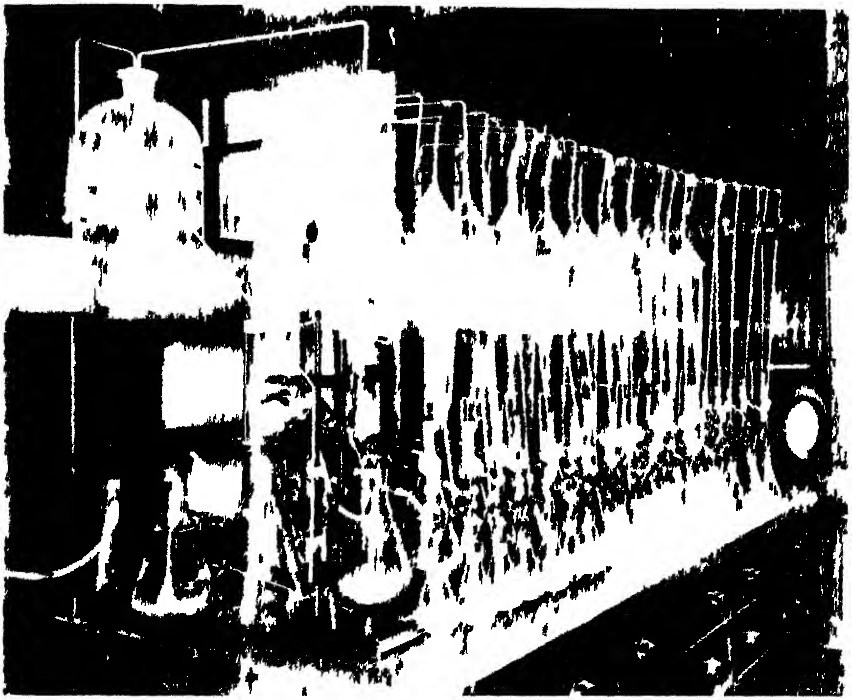
3. The method of titrating the solution is detailed.
4. Results obtained with the apparatus are tabulated.
5. The advantages of the apparatus and the methods are pointed out.

REFERENCES

(1) CLARK, W. M. 1922 The Determination of Hydrogen Ions. Baltimore, Md.
(2) LEDIG, P. J. 1924 Absorption of carbon dioxide and ammonia from gas bubbles. *Indus. Engin. Chem.* 16: 1231–1233.
(3) MARSH, F. W. 1925 A test of Ascarite, a carbon dioxide absorbent, as its own drier. *Jour. Assoc. Off. Agr. Chem.* 8: 442–444.
(4) POTTER, R. S., AND SNYDER, R. S. 1916 Carbon dioxide production in soils and carbon and nitrogen changes in soils variously tested. Iowa Agr. Exp. Sta. Res. Bul. 39.
(5) SIMPSON, S. G. 1924 A mixed indicator for carbonate-bicarbonate titrations. *Indus. Engin. Chem.* 16: 709–710.

PLATE 1

THE COMPLETE APPARATUS FOR THE MEASUREMENT OF CARBON DIOXIDE EVOLVED FROM SOILS



A BACTERIOLOGICAL STUDY OF A SOIL TYPE BY NEW METHODS

H. J. CONN

New York Agricultural Experiment Station

Received for publication December 1, 1927

Various methods have been adopted in the past for obtaining information concerning bacteria present in soil, none of which as yet have yielded an abundance of practical information. Among such methods have been: the plate method of counting bacteria in soil; the Remy-Löhnis method of inoculating soil into various culture media; the Hiltner-Störmer dilution method of counting the groups of bacteria present; and the microscopic technic proposed by the writer. It is hardly too much to say that each decade of soil bacteriological investigations has seen new methods develop and the end of the decade has seen them to a large extent discredited. Recently, however, Winogradsky (5, 6) has shown a way of applying the microscopic method of study which seems to have considerable value.

Winogradsky's method of applying the microscopic technic has recently been employed in this laboratory for comparing four different soil types (4). It is the purpose of this article to show how this technic, in combination with the plate method, has been used in the study of one of the four soil types in question.

The soil selected for this work is known by the Bureau of Soils as Hoosick coarse sandy loam. The spot selected was located near Kinderhook, N. Y. in the Hudson Valley. The soil survey of this area has not yet been published, but the following statement concerning this soil has been supplied by the Bureau of Soils field agent who has been studying the soils of the locality.

HOOSICK COARSE SANDY LOAM, NO. 29

The surface soil of the Hoosick coarse sandy loam to a depth of 8 to 10 inches is light brown, or grayish brown to slightly reddish brown in color. The surface soil is friable and loose in structure and contains considerable amounts of small fine gravels or flakes of shales and slate fragments.

The upper subsoil to a depth of 20 to 25 inches is typically yellowish brown, brownish yellow to slightly reddish brown in color. The texture is a coarse sandy loam, loose and porous in structure. The lower subsoil grades into grayish brown to brownish gray and becomes more gray with depth. The soil material of this type is loose and friable throughout the soil section. The substratum represents stratified beds of sands and rounded gravels. The gravel content becomes higher with depth of soil material.

The abundance of small shale and slate fragments and quartz sand grains on the surface gives it a very gritty feel.

This type is extensive in the central northern part of the county, and occurs in close association with the sandy loam type of the Hoosick series. It is well developed in the region of Kinderhook.

The soil material was laid down under the same conditions as the sandy loam type and it occupies terraces, bench lands, and outwash plains. The topography is smooth, gently sloping to slightly undulating. Drainage is largely internal and is good to excessive and the soil is inclined to be droughty. *The soil is low in organic matter and shows no lime in the 3-foot section.*

Practically all of the type has been cleared and is used for general farm crops and for fruit. In the vicinity of Kinderhook much of this soil is planted to fruit and the yields are good. General farm crops do not produce as well as the gravelly loam soil.

This soil was selected for study because of certain interesting cultural characteristics. These characteristics are referred to briefly in the sentence italicized in the above quotation. The soil is, in fact, distinctly acid; but when first cultivated after lying idle for a series of years, liming alone is not enough to bring it into good crop-producing power. After sufficient cultivation and cropping, however, to build up a humus content, this soil becomes highly productive. Its humus is rapidly depleted and the proper handling of the soil requires very frequent incorporation of organic matter.

These properties make the soil an easy one to exhaust temporarily; but when in such a condition, it responds very strikingly to fertilization.

This soil is located at a considerable distance from the Station at Geneva, where the laboratory work was done. The samples studied in this work were obtained from the branch station at Hudson.[1]

EXPERIMENTAL

Study of samples of orchard soil

The first samples of soil sent in from Kinderhook for this investigation were received at various dates from April to October in 1925. The first step in their examination was in every case to make gelatin plates from them.

The gelatin used in plating this soil was 12 per cent Bacto Gelatin in tap water, no additional nutrient material being furnished, but with the reaction adjusted to pH 7.0. The plates were incubated for 7 days at 18°C. before they were studied. The counts obtained from these plates are given in table 1.

There is nothing very striking about these figures. In two instances the numbers were higher in the unfertilized soil, in the other case, in the nitrate-treated soil. All the counts were slightly lower than those obtained on corresponding dates from samples of the local soil at the Geneva Station (Dunkirk silty clay loam), but not so low as to seem unusual. The types of colonies developing were almost identical with those on plates made from the soils with which the writer was more familiar.

[1] These samples were taken under the personal supervision of H. B. Tukey of the horticultural division, who was located at Hudson at the time this work was done. Acknowledgment to him for his cooperation is hereby given.

The first clue as to any peculiarity of the bacteria in this soil was obtained when cultures were isolated from these plates. In this study, however, little attention was paid to the large colonies present on the plates. These large colonies were such types as *Bacillus mycoides*, *B. cereus*, and *B. megatherium* or sometimes *Pseudomonas fluorescens*. Such organisms are so universally present in soils that it seemed doubtful whether any differences between this soil and any other could be brought out by taking consideration of them alone. Their colonies, moreover, were never very numerous in the soil under investigation. Colonies of Actinomycetes were always present in considerable abundance, varying from 15 to 55 per cent of the total flora shown on the plates. This relative abundance of Actinomycetes was rather high, but not abnormally so. No qualitative study was made of these organisms, although it is admitted that such a study might show as interesting results as the investigation of the group that was actually selected for the purpose.

The organisms chosen for special study were the bacteria producing punctiform colonies on the plates. Such organisms, which are of considerable interest to the writer at present, have been discussed in a recent publication (2). One group of these punctiform colony types which has been found present in most of the soils investigated is characterized by its peculiar morphology. These organisms grow as short rods for one or two days on a fresh agar slant and then become spherical, growing thereafter very much like micrococci. In the publication just referred to these organisms were called "coccus-forming rods." The only known method to determine whether they are present in a soil is to isolate a series of cultures from the punctiform colonies developing on the plates, then to make microscopic preparations from them each day for a short time to learn whether the characteristic change in morphology occurs.

TABLE 1

Plate counts of orchard soil, unfertilized and nitrate-fertilized

Figures indicate numbers of colonies per gram of moist soil

DATE	UNFERTILIZED SOIL	SOIL TO WHICH NITRATE WAS ADDED ABOUT MAY 1, 1925
April 20, 1925	3,600,000	....
May 6	5,000,000	3,600,000
May 28	6,000,000	9,600,000
July 22	4,600,000	3,600,000

A study of this sort was made of the cultures from the punctiform colonies appearing on the plates of the Hoosick soil. It was found in this study that the coccus-forming rods were not absolutely lacking, but were distinctly fewer than in any other soil where a search for them had been made.

To learn whether this fact indicated that the bacteria in question were not suited for growth in this soil, a few cultures of this type were inoculated into

test tubes of soil that had been sterilized in an autoclave for ½ hour at 15 pounds pressure. For comparison, three other types of soil were inoculated with these same organisms at the same time. They were incubated at 25°C., and after different periods of incubation varying from 1 day to 4 days, microscopic preparation were made and stained according to the procedure previously described by the writer (1, p. 3) and discussed in more detail below (p. 269). Of the soils selected for comparison with the Hoosick soil, one was acid in reaction, one was distinctly alkaline, and the third was about neutral. It was found that the organisms used for inoculation practically failed to develop in either of the acid soils but developed abundantly in the other two.

This experiment was then repeated several times with the same soils after 1 per cent calcium carbonate had been added. The first time the test was made under such conditions it was found that these orgaisms grew equally well in all four soils (4, p. 26). Upon repetition of the work, however, they were never found to thrive in the Hoosick soil unless in addition to the lime some source of nitrogen available to these organisms were added.

From this it was concluded that the only difference thus brought out between the bacterial flora of the soil under investigation and that of the other soils with which it was compared was that certain organisms which are unable to grow in an acid soil were not abundant in it. As far as could be learned by the plate method, the same types of organisms, except for the coccus-forming rods, developed in this soil as in the other soils.

Study of soil from an uncultivated field

In October, 1925, a larger lot of soil was received from the same locality as that from which the preceding samples were taken. In this case, however, the soil was obtained from a field that had been uncultivated for a long period. This soil was taken up in three separate layers representing respectively the upper 2 inches, the next 6 inches, and the succeeding 8 inches of soil. The soil layers were shipped separately and when used in the laboratory they were placed in pots or boxes with the layers in the same order as in the field from which they were taken.

It was observed at the outset that the plate count obtained from this soil was extremely low; and after the first week it dropped still lower. For about a month it varied from 900,000 to 2,000,000 per gram (see table 2).

Three different lines of treatment were tried to determine whether the flora could be made more nearly normal either in numbers or in kinds. The first was the addition of potassium nitrate in quantities varying from 0.2 gm. to 1 gm. per 600 gm. of soil. This was done because the response to nitrate fertilization in the field had always been pronounced. These pots were kept in the laboratory with their moisture content restored every few days to about 20 per cent of the dry soil. The results, as indicated in table 2, were entirely negative. Only on one date (December 10) was the count of a nitrate-treated pot over 3,500,000; and on that occasion the count in the untreated check was

TABLE 2

Plate counts of unlimed field soil, kept in the laboratory in pots to which varying amounts of KNO_3 were added

Figures indicate numbers of colonies per gram of moist soil

DATE	COUNTS IN POTS TO WHICH ON DECEMBER 2, 1925 THE FOLLOWING QUANTITIES OF KNO_3 WERE ADDED PER 600 GM. SOIL								
	0 gm.	0.2 gm.	0.3 gm.	0.4 gm.	0.5 gm.	0.6 gm.	0 75 gm.	0.8 gm.	1.0 gm.
October 29, 1925	3,800,000								
November 10	2,000,000								
November 21	900,000								
December 3	2,000,000				1,400,000				1,200,000
December 5	900,000				1,100,000				3,500,000
December 10	6,000,000								7,500,000
December 30		1,200,000	1,300,000	1,400,000	2,000,000	3,000,000	3,300,000	1,800,000	2,600,000

almost as high (6 million as against 7½ million in the presence of nitrate). As the count of the nitrate-treated pot had dropped again on December 30, it seems that the moderately high count on December 10 must have been due to some temporary factor independent of the nitrate treatment. Not only were the counts low, but the types of colonies were the same in the treated and untreated soils; and the same types of cultures were isolated in either instance.

By this time it was suspected that the acid reaction might be holding the count down. Accordingly another pair of pots was prepared on December 11, to each of which was added 5 gm. of $CaCO_3$ for 600 gm. of soil; one pot had no further addition, the other was given 1 gm. of nitrate. As in the previous experiment, the moisture content was maintained by frequent additions of water. The plate counts are given in table 3. It will be seen that the counts are distinctly higher than without liming, and on December 23 had risen to 56 and 64 millions respectively. This initial increase was followed by a drop in numbers; but at no time did the counts reach the low level observed in the

TABLE 3

Plate counts of field soil, to which 5 gm. $CaCO_3$ was added per 600 gm. soil; kept in pots with and without nitrate

Figures indicate numbers of colonies per gram of moist soil

DATE	COUNT IN POT WITHOUT NITRATE	COUNT IN POT TO WHICH 5 GM. $CaCO_3$ WAS ADDED DECEMBER 11, 1925
December 11, 1925	17,000,000	11,800,000
December 23	56,000,000	64,000,000
January 6, 1926	18,000,000	32,000,000
February 3	13,000,000	11,000,000

unlimed soil. In the first and last instances the soil without nitrate had the higher count; in the second and third, the one with nitrate. It was plain from this that correction of the soil reaction allows better growth of the bacteria. There was also some evidence that the types of organisms were different after liming; but the coccus-forming rods, always so conspicuously absent in this soil, were still lacking. No differences were observed between the kinds of organisms in the nitrate-treated soil and in the soil without nitrate.

Following this test, work was dropped on the soil for a few months. In the meantime the soil was kept in a box in the laboratory and became almost air-dry. In June, 1926, it was moistened again and another series of plate counts made (table 4, column 2). It was found that the bacteria capable of developing on the gelatin plates were noticeably more numerous, running from 4 to 9 millions per gram. This was about as high as previously observed in the orchard soil. Rather surprisingly there had also been a change in the kinds; and now the coccus-forming rods previously absent, were found in moderate

abundance. Evidently the nature of the flora had been changed considerably during the few months storage. This change was unexpected; but it has been concluded that it correlates very well with the field results showing that the soil bears very poor crops when first cultivated but becomes noticeably more productive after a season or two of cultivation.

At the same time that these plate counts were made, an experiment was run to observe the effect of humus-forming material on the flora. The plates were made on the same dates as those of the untreated soil and the results are tabulated with the latter data in table 4. To one pot rotted manure was added, to the other dried peat. The former treatment had no distinct effect on the plate count; but the latter caused an increase to over 20 million per gram. No effect of either treatment was observed on the kinds of bacteria or on their relative abundance.

Apparently the factors causing increases in the total flora capable of developing on gelatin, as brought out in this work, are: liming, addition of peat,

TABLE 4

Plate counts of unlimed field soil kept in the laboratory in pots to which manure or peat was added

Figures indicate numbers of colonies per gram of moist soil

DATE	COUNTS IN SOIL TO WHICH HAD BEEN ADDED		
	Nothing	Rotted manure	Dried peat
June 12, 1926	4,200,000	4,200,000	10,000,000
June 15	7,000,000	8,000,000	28,000,000
June 18	9,000,000	3,000,000	15,000,000
June 23	4,000,000	4,700,000	22,000,000
June 25	4,000,000	6,500,000	25,000,000

and storage after aeration in fairly dry condition. Of these, the last only had any effect on the kinds of bacteria, so far as could be shown by the methods used.

Microscopic study of the soil flora

As a further means of studying the peculiarities of this soil, it was compared by the direct microscopic method with the same three soils referred to above (p. 266). These soils included another unproductive acid soil—Volusia silt loam—and two neutral or alkaline soils—Dunkirk fine sand and Dunkirk silty clay loam. The last mentioned soil is of high productivity, and is the type present over a large section of the Station farm at Geneva.

The microscopic study was made by the method of application developed by Winogradsky (5, 6). This method is to learn to recognize the organisms comprising the normal or "autochtonous" flora of the soil, and then to add different nutrient ingredients, observing the types of organisms caused to

multiply by such treatment. The food ingredients used in this experiment were peptone, mannite, starch, and soybean meal. Winogradsky has employed this method chiefly to study the types of bacterial reaction which follow the different kinds of treatment; in the present work, on the other hand, the chief object was to bring out differences between the different soils. The results are given in detail in a recent publication (4). They will be discussed here only so far as they bear on the peculiarities of the Hoosick soil.

The method of making and staining the films of soil suspension is as follows:

Make a suspension of soil in nine times its weight of a 0.015 per cent solution of gelatin. Smear a drop of this on a thin film on a slide. Immerse the slide for from 1 to 3 minutes in a 40 per cent solution of acetic acid or a strong solution of hydrochloric acid. Wash off the excess acid briefly, and dry the slide on a flat surface over a boiling water bath. While the slide is still on the water bath, cover the film with a 1 per cent aqueous solution of rose bengal, phloxine B, or erythrosin Y, and allow it to stain for about 1 minute. In this laboratory, rose bengal has seemed to give the best results of the stains just named, and was used throughout the present work.

By using this staining technic, it was found possible to classify the bacteria observed into six groups which were called: large coccoid forms, small coccoid forms, long small rods, short small rods, large rods, and bacterial endospores.

It was learned that in a control soil (i.e. with no added material) all these morphological types occurred in about equal numbers, except that large rods and spores which were relatively scarce. This was true with all four soils, no peculiarities of the Hoosick soil being noticeable; nor were the two acid soils any different from the non-acid soils by this method of examination.

This similarity between the various soils was no longer noticeable, however, when the examinations were made after adding any of the ingredients named above. In nearly every test it was found that the Hoosick soil made a different response to the treatment from either of the Dunkirk soils, but very similar to that of the Volusia silt loam, the other acid soil. This difference was brought out most strikingly by the soybean treatment; following the addition of this ingredient, in fact, the Hoosick soil failed to show the presence of certain small short rods which were the predominant forms in the other soils. It was found, moreover, that nearly all these differences disppeared when 1 per cent of calcium carbonate were mixed with the soil so as to overcome the acid reaction. This suggested that the primary difference between the Hoosick soil and the Dunkirk soils was in reaction, not in the types of bacteria present.

In one instance, namely, following peptone treatment, the addition of calcium carbonate did not cause the difference to disappear. Under this treatment, the Hoosick soil was characterized by the development of certain very short rods that did not appear in the other soils. This implied an actual difference in the flora rather than a mere difference in reaction.

It is, of course, altogether too much to claim that these results have any deep significance. They merely indicate that bacteriological differences between this soil and the others do exist and that this line of investigation may serve to establish their nature.

DISCUSSION

The use of the plate method for counting and classifying the bacteria of soil was introduced in the early days of soil bacteriology. Later it fell into disrepute, partly because it does not give satisfactory information as to the kinds of microörganisms present and partly because it overlooks all but a small fraction of the bacteria in the soil. This latter objection to the plate method was particularly emphasized when the writer proposed a microscopic method of studying soil bacteria and showed how much larger counts could be thus obtained than by culture plates. In spite of the writer's insistence on this point, the plate method of studying soil bacteria has distinct use. The plate method and the microscopic method were employed together in the present work.

It must be realized that microörganisms in soil cannot be counted accurately by either the culture plate or the microscope. The plate method overlooks those that do not grow on the media employed; the direct microscopic method excludes those that for mechanical reasons cannot be made visible in a dried film of soil suspension, and does not provide good distinction between the smallest bacteria and tiny particles of organic matter. As a result, each method must be regarded as furnishing merely an estimate; both estimates must be compared and the results interpreted, if a true idea of the numbers is desired.

Similarly, if qualitative information is wished, the two methods must be used in conjunction. The culture plate, to be sure, overlooks large groups of soil bacteria; but of those that do appear on the plates, it allows much better classification (by appearance of the colony) than can be obtained under the microscope. When the microscopic technic was proposed it seemed unlikely to be of much use in yielding qualitative information. Fortunately, however, Winogradsky's method of employing it does furnish some information as to kinds as well as numbers. It can accordingly be used, side by side with the plate method, for making a qualitative study of the bacteria in soil.

The soil studied in the present work seemed a good one to study by these methods, as it was realized to be quite distinctive in regard to microbiological processes; and if the methods are of value, they should show differences in regard to microflora between this soil and other soils more typical in their characteristics.

The investigations made on this soil are still incomplete; but they do bring out certain distinctive features concerning its microbial population. The plate method shows that the soil contains very few microörganisms capable of developing on the medium employed (gelatin) when it has remained for a long period in an uncultivated state; the microscope shows that the total flora is also low. Both methods show striking increases in numbers when the soil has been cultivated (or otherwise aerated); but the increases develop slowly and appear only after several months. As these increases occur even if the

soil is not limed, it is shown that its meager flora under undisturbed conditions is not due wholly to its acid reaction.

The microscope further shows that the response made by the microörganisms to the addition of various nutrient materials (peptone, mannite, starch, and soybean meal) is quite different from that occurring in two neutral or alkaline soils with which it has been compared; but it is very similar to that observed in another acid soil. Some of these differences were found to disappear if 1 per cent $CaCO_3$ is present. A striking exception to this, however, was the response shown to the addition of peptone, either with or without calcium carbonate. With this treatment this soil showed a striking increase of very small short rods. Undoubtedly they must take part in the decomposition of the peptone; and their presence in this soil may explain why organic matter added to it disappears so rapidly.

Future work should show whether the organism appearing after peptone treatment always shows up in this soil; and if so, it should be isolated and studied by cultural methods.

SUMMARY

A soil from the Hudson valley, known by the Bureau of Soils as Hoosick coarse sandy loam has been studied by bacteriological methods. This soil was chosen for the study because organic matter added to it always disappears quickly and the productivity of the soil can be maintained only by frequent additions of humus-forming material. This seems to indicate unusual microbial activity. The soil is distinctly acid in reaction.

The study was made partly by plating in gelatin and isolating cultures, and partly by the microscopic technic. In this study it was compared with three other soils, the object being to look for any abnormality in its flora or the activitities of the organisms present.

The results so far obtained are preliminary only and it is planned to pursue the investigation further. They merely indicate that bacteriological differences between this soil and the others studied do exist and that the methods employed may serve to establish their nature. The methods are now published together with the results so far obtained with the hope that this line of attack may be suggestive to others.

REFERENCES

(1) Conn, H. J. 1918 The microscopic study of bacteria and fungi in soil. N. Y. Agr. Exp. Sta. Tech. Bul. 64.

(2) Conn, H. J. 1925 Soil flora studies: VI. The punctiform-colony-forming bacteria in soil. N. Y. Agr. Exp. Sta. Tech. Bul. 115.

(3) Conn, H. J. 1926 An improved stain for bacteria in soil. *Stain Technol.*, 1: 125.

(4) Thatcher, Lida M., and Conn, H. J. 1927 The bacterial flora of four soils compared by the direct microscopic method. *N. Y. Agr. Exp. Sta. Tech. Bul.* 129: 11–27.

(5) Winogradsky, S. 1924 Sur l'étude microscopic du sol. *Compt. Rend. Acad. Sci.*, 179: 367–371.

(6) Winogradsky, S. 1925 Études sur la microbiologie du sol: I. Sur la méthode. *Ann. Inst. Pasteur* 39: 299–354.

THE EFFECT OF GROWING PLANTS ON SOLUBILITY OF SOIL NUTRIENTS[1]

W. H. METZGER[2]

Kansas State Agricultural College

Received for publication December 1, 1927

INTRODUCTION

The question as to whether plants are capable, through the solvent action of excretions from their roots, of dissolving their own plant-food materials and the extent to which this may be accomplished has been a perplexing problem. The theory of acid excretions of roots is old, and although it is still unsettled, it is now quite generally believed that carbon dioxide is the only substance excreted by plant roots which is capable, under normal conditions, of exerting an appreciable solvent action on insoluble minerals in the soil.

In the work reported here an attempt was made to measure the extent to which certain soluble substances appeared at the points of contact of roots and soil.[3]

MATERIALS AND METHODS

Soil samples used in this work were taken from the campus and college farm of the Kansas State Agricultural College. All of the soils used were silt loam in texture. The greenhouse work was done with a reddish-brown silt loam, which contained considerable fine sand and was low in organic matter. It had been cropped to wheat the previous season. The plants used in the work were wheat, corn, kafir, cowpeas, buckwheat, lettuce, pine trees, and apple trees.

The general method employed was carefully to remove the soil from above the roots and with a piece of sheet metal bent into a U-shape, or with a spatula, to secure a small amount of the soil, including a core about an inch in diameter, in immediate contact with the roots. The check samples were taken within 2 to 4 inches of where the root samples were taken, the purpose being to secure them adjacent to the immediate feeding zone of the roots. The samples so obtained were taken at once to the laboratory in closed containers and the desired determinations made promptly, so that the soil was not allowed to dry. Moisture determinations were made and all results were expressed on the basis of oven-dry soil.

[1] Contribution No. 173 from the Department of Agronomy of the Kansas Agricultural Experiment Station.

[2] Part of a thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at the Kansas State Agricultural College.

[3] The writer acknowledges his indebtedness to Dr. F. L. Duley under whose direction this work was outlined and pursued, for his constant interest and many helpful suggestions and criticisms.

REVIEW OF LITERATURE

The work of Sachs (20), Czapek (6), Stoklasa and Ernest (22), and Aberson (1) has demonstrated that carbon dioxide is excreted by plant roots and that it is the only substance excreted, under normal conditions, in quantities sufficient to exert a solvent action on soil minerals.

Kossovitsch (10), Stoklasa and Ernest (23), Lau (12), Stoklasa (24), and Parker (16) showed that considerable quantities of carbon dioxide are excreted by plant roots, amounting to almost one-third gram per plant per day in some cases.

Parker (17) concluded that carbon dioxide excretions have little effect on the yield, ash content, and calcium content of plants. Hoagland (8) criticized this work on the basis that it was done in sandy soil practically free of colloids and that the conclusions are therefore probably not justified when applied to most soils.

Ballentine (2), Kossovitsch (11), Prainishnikov, (18, 19), Merrill, (15), Headdon (7), Schreiber (21), Jordan (9), Truog (26), Bauer (4), and Marais (14) found certain plants capable of obtaining plant-food from relatively insoluble minerals in sand cultures. Certain other plants, including cereals, did not thrive in such cultures.

Lyon and Buckman (13) and Truog (25) point out that excreted carbon dioxide works at maximum efficiency because of intimate contact of root and soil particle and constant removal of the products of reaction.

We may conclude from this work that it has been conclusively proved that plants excrete carbon dioxide into the soil from their roots in considerable quantities. The extent to which excreted carbon dioxide functions as a soil solvent is a question upon which there is little direct evidence, and such evidence as has been presented is conflicting.

EXPERIMENTAL PROCEDURE

The measurement of the concentration of water extracts of soil samples taken from around roots as compared with that of other samples taken away from roots was the general plan adopted for the work. Gravimetric determinations of total salts were attempted but did not prove satisfactory as it was necessary to evaporate large quantities of solution in order to detect differences. Absorption of materials by the plant further complicated the drawing of conclusions from such work. Measurement of electrical conductivity also proved an unsatisfactory method because of the influence of differences in hydrogen-ion concentration. Measurement of bicarbonates in such samples gave the most consistent results and appeared to be the most reliable method of comparison.

EFFECT OF THE PLANT ON CONCENTRATION OF BICARBONATES

In these determinations both field and greenhouse soil samples were used. The samples were taken in the manner previously described and extracted with distilled water in the ratio of 1 to 5. After 10 minutes' agitation the suspension was filtered, with a Pasteur-Chamberland filter.

Bicarbonates were determined in the soil extracts by the double titration method, phenolphthalein and methyl orange being used as indicators. Bicarbonates were expressed as parts of carbon dioxide (in bicarbonates) per million parts of oven-dry soil.

RESULTS OF DETERMINATIONS OF BICARBONATES

The results of 66 determinations of bicarbonates which were made are listed in table 1.

TABLE 1

Concentration of bicarbonates

PLANT	TRIAL NUMBER	BICARBONATES (CO_2 IN BICARBONATES P P M OF OVEN-DRY SOIL)	
		Root samples*	Checks†
Corn	1	58	52
	2	33	15
	3	22	30
	4	75	55
	5	77	72
	6	65	39
	7	75	35
	8	80	32
	9	57	44
	10	61	35
	11	53	48
	12	107	81
	13	86	59
	14	70	54
	15	107	76
	16	130	80
	17	135	65
	18	119	55
	19	107	80
	20	72	42
	21	76	53
	22	55	41
	23	66	77
	24	60	60
	25	60	66
	26	66	60
	27	95	82
	28	99	77
	29	82	77
	30	82	82
	31	66	60
	32	72	66
	33	75	60
	34	86	48
Wheat	1	77	69
	2	64	57

PLANT	TRIAL NUMBER	BICARBONATES (CO_2 IN BICARBONATES P P M OF OVEN-DRY SOIL)	
		Root samples*	Checks†
	3	66	63
	4	82	50
	5	103	84
	6	65	61
	7	73	87
	8	60	56
	9	47	64
	10	48	37
	11	77	55
	12	77	65
	13	110	82
	14	121	85
Kafir	1	59	40
	2	60	82
	3	77	82
	4	115	77
	5	126	82
	6	104	88
Apple	1	119	110
	2	124	105
	3	122	106
	4	122	106
	5	73	73
	6	73	73
Pine	1	143	102
Lettuce	1	285	202
Cowpeas	1	91	55
	2	72	60
Buckwheat	1	55	34
	2	41	34

* Soil samples taken near roots.

† Soil samples taken 2 to 4 inches away from the roots.

RELATIVE CONCENTRATION OF BICARBONATES

The relative concentrations are of much greater interest in this discussion than are the actual concentrations shown in table 1. The data in table 1 are summarized in table 2, which shows much more clearly the effect of the plant on the concentration of bicarbonates.

That a higher concentration of bicarbonates exists around roots than at a short distance from them seems fairly evident from these results. The advantage in favor of the root samples is noticeably consistent and when the plants were in the blooming and fruiting stages, the differences were more marked.

RELATION OF AGE OF PLANT TO CONCENTRATION OF BICARBONATES

The most interesting and perhaps the most conclusive phase of the work on bicarbonates is the relationship established between age of plants and concentration of bicarbonates. A series of 26 determinations of bicarbonates with corn, 13 with wheat, and 7 with kafir were made on the same soil in greenhouse work.

TABLE 2

Summary of bicarbonate determinations

PLANT	NUMBER OF DETERMINATIONS	NUMBER OF TIMES BICARBONATES OF ROOT SAMPLE EXCEEDED CHECK	NUMBER OF TIMES BICARBONATES OF CHECK SAMPLE EXCEEDED ROOT SAMPLES	NUMBER OF TIMES CONCENTRATIONS WERE EQUAL
Kafir	6	4	2	...
Wheat	14	11	3	...
Corn	34	28	4	2
Pine	1	1	0	...
Lettuce	1	1	0	...
Cowpeas	2	2	0	...
Buckwheat	2	2	0	...
Apple	6	4	0	2
Totals	66	53	9	4

The corn, wheat, and kafir were planted in flats and large pots in the greenhouse on November 29. Determinations were made on various dates during the growth of these plants.

The final determinations were made on corn after the ears were almost mature, and on wheat and kafir just as they were beginning to head. There was a considerable period during the middle stages of growth of the wheat when no determinations were made.

Figures 1, 2, and 3 show graphically the quantities of bicarbonates in soil samples taken near the roots and in check samples taken a few inches from the roots at various stages of growth of the three crops involved. The increase of

concentration of bicarbonates in the soil around roots became pronounced when the blooming and fruiting period of the crop was reached. This, it will be observed, was the case with each of the three crops studied. Corn, which grew almost to complete maturity, showed a decline in the final determinations. Samples were not available for determinations with wheat and kafir beyond the early heading stage and, therefore, it could not be determined whether a similar decline would be shown with these crops.

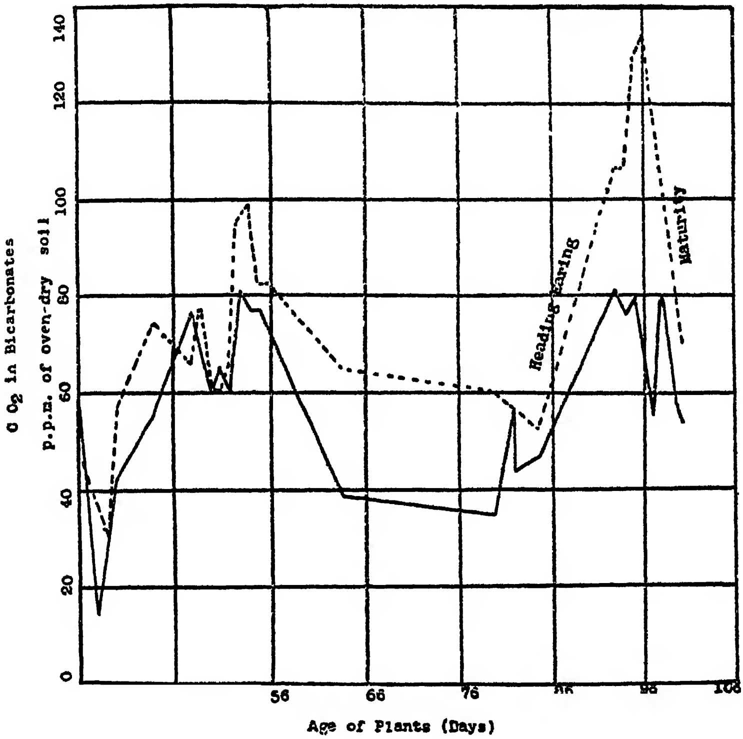


FIG. 1. AGE OF CORN PLANTS AND CONCENTRATION OF BICARBONATES

———————Bicarbonates in soil away from roots
- - - - - - - -Bicarbonates in soil around roots

With both wheat and corn an early increase in bicarbonates was followed by a decrease during the middle stages of growth. There was considerable fluctuation also in the early determinations, which may have been caused by low temperatures in the greenhouse. The temperature record of the greenhouse shows temperatures as low as 50–60°F. just previous to some of the determinations having a considerably reduced concentration. The final increase and maximum at the blooming and fruiting stage was followed, though less pronouncedly, by an increase in bicarbonates in the checks. This was probably

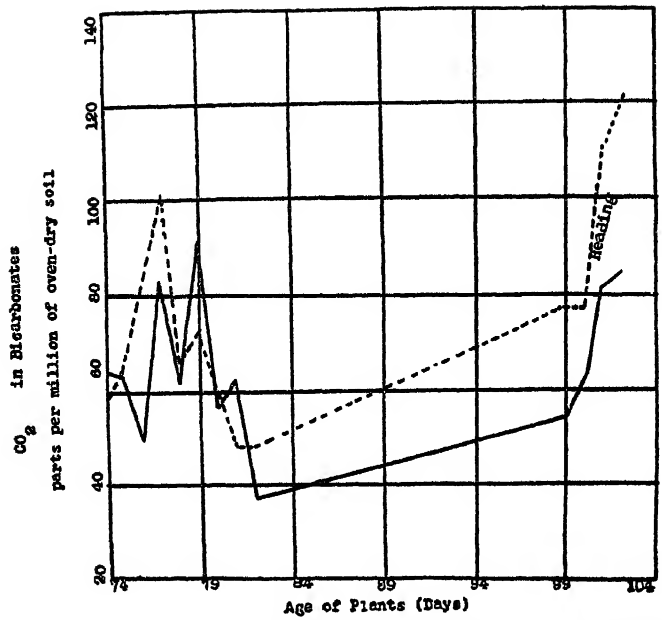


FIG. 2. AGE OF WHEAT PLANTS AND CONCENTRATION OF BICARBONATES

——————Bicarbonates in soil away from roots

——————Bicarbonates in soil around roots

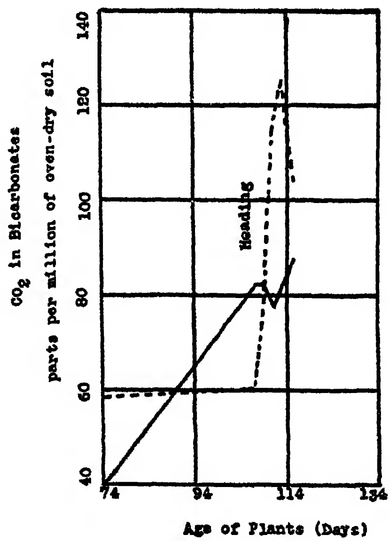


FIG. 3. AGE OF KAFIR PLANTS AND CONCENTRATION OF BICARBONATES

——————Bicarbonates in soil away from roots

——————Bicarbonates in soil around roots

because the higher rate of carbon dioxide excretion from roots at that period increased the concentration of carbon dioxide in the soil air and soil solution, generally, and thus more bicarbonates were formed at a short distance from the roots at this time than at other stages of the plant's growth.

The occurrence of a maximum concentration of bicarbonates around roots at blooming and fruiting of the plants might be expected, considering the results secured by Turpin (27), Barakov (3), and others, showing the maximum excretion of carbon dioxide by roots at this stage of growth. This is in accord, also, with the results of Burd and Martin (5), which showed a higher concentration of the bicarbonate ion in the soil solution of a cropped soil at the end than at the beginning of the growing season.

These results seem to indicate that plants are capable, through carbon dioxide excretions from their roots, of supplementing the dissolving processes occurring in the soil as the results of bacterial activity and other biological processes. During the time when the plant is making rapid growth and consequently heavy demands on the soil solution, the solvent action of the plant root excretions may be of considerable importance.

SUMMARY

The work reported in this paper was undertaken to study the effect of plants in rendering soluble the mineral nutrients of the soil. This was done by removing soil samples from close proximity to the roots and other samples at a distance of from 2 to 4 inches from the roots and measuring the relative concentration of water extracts of the two samples.

Determinations of bicarbonates proved the most satisfactory method of measurement of such solvent action. Consistent differences were secured in concentration of bicarbonates, the samples from around roots showing the higher concentration. This was true with both greenhouse and field samples.

It was shown with corn, wheat, and kafir that the maximum difference in concentration of bicarbonates occurred at the fruiting period of the plants.

Of 66 determinations with various plants, 53 showed higher concentration of bicarbonates in samples from around roots, 4 showed equal concentration, and 9 lower concentration than in samples taken at a short distance from the plant roots. This appears to be additional evidence that plants through the CO_2 excretions from their roots are able to exert a measurable solvent action on the soil minerals.

REFERENCES

(1) ABERSON, J. H. 1908 The acid excretion of roots. *Meded. Rijks. Hoogere Land, Tuin en Boschbouwsch.* 1: 1–18; *Jahrb. Wiss. Bot.* (*Pringsheim*) 47: 1: 1–56; Abs. in *Exp. Sta. Rec.*, 22: 328.

(2) BALLENTINE, W. 1889 Experiments with feldspar as a source of potash. Me. Agr. Exp. Sta. Ann. Rpt. 1889: 143.

(3) BARAKOV, P. 1910 The carbon dioxide content of soils during different stages of growth of plants. *Zhur. Opuitn. Agron.* (*Russ. Jour. Exp. Landw.*) 11: 321–343. Abs. in *Exp. Sta. Rec.* 23: 523.

(4) BAUER, F. C. 1921 The relation of organic matter and the feeding power of plants to the utilization of rock phosphate. *Soil Sci.*, 12: 21–41.

(5) BURD, J. S., AND MARTIN, J. C. 1924 Secular and seasonal changes in the soil solution. *Soil. Sci.* 18: 151–167.

(6) CZAPEK, F. 1896 Für Lehre von dem Wurzelausscheidungen. *Jahrb. Wiss. Bot.* 29: 321.

(7) HEADDEN, W. P. 1901 The soil. Colo. Agr. Exp. Sta. Bul. 65.

(8) HOAGLAND, D. R. 1925 Physiological aspects of soil solution investigations. *Cal. Agr. Exp. Sta. Hilgardia.* 1: 242, 248

(9) JORDAN, W. H. 1912 Studies in plant nutrition. N. Y. Agr. Exp. Sta. Bul. 358.

(10) KOSSOVITSCH, P. S. 1898 Report of the agricultural chemical laboratory of the Ministry of Agriculture and Imperial Domains in St. Petersburg. Abs. in *Exp. Sta. Rec.* 13: 235.

(11) KOSSOVITSCH, P. S. 1904 Quantitative determination of the carbon dioxide secreted by roots during growth. *Zhur. Opuitn. Agron.* (*Russ. Jour. Exp. Landw.*) 5: 482–493

(12) LAU, E. 1906 Investigations on the composition of the air of cultivated soils. *Luft. Inaug. Diss. Rostock*, p. 34. Rev. in *Zentbl. Agr. Chem.* 37: (1908) 433–434. Abs. in *Exp. Sta. Rec.* 20: 817.

(13) LYON, T. L., AND BUCKMAN, H. O. 1922 The Nature and Properties of Soils. New York.

(14) MARAIS, J. S. 1922 The comparative agricultural value of insoluble mineral phosphates of aluminum, iron, and calcium. *Soil Sci.* 13: 355–411.

(15) MERRILL, L. H. 1895 Investigations on the foraging powers of some agricultural plants for phosphoric acid. Me. Agr. Exp. Sta. Ann. Rpt. 1895: 10–18; 1898: 64–74.

(16) PARKER, F. W. 1924 Carbon dioxide production of plant roots as a factor in the feeding power of plants. *Soil Sci.* 17: 229–247.

(17) PARKER, F. W. 1925 The carbon dioxide of the soil air as a factor in the absorption of inorganic elements by plants. *Soil Sci.* 20: 39–44.

(18) PRIANISHNIKOV, D. N. 1899 Is the phosphoric acid of mineral phosphates available to cultivated plants? *Izv. Moscow Selsk. Khoz. Inst.* 5: 90–110; *Ann. Agron.* 25: 177–187. Abs. in *Exp. Sta. Rec.* 11: 527.

(19) PRIANISHNIKOV, D. N. 1906 Feldspath und Glimmer als Kaliquellen. *Landw. Vers. Sta.* 63: 151.

(20) SACHS, J. 1906 Auflösung des Marmors durch Mais-Wurzeln. *Bot. Ztg.* 18: 117–119.

(21) SCHREIBER, C. 1902 The solvent power of different plants for mineral phosphates. *Rev. Gén. Agron.* (Louvain) 11: 337–391. Abs. in *Exp. Sta. Rec.* 14: 430.

(22) STOKLASA, J., AND ERNEST, A. 1861 Beiträge zur Lösung der Frage der Chemischen Natur des Wurzelsekretes. *Jahrb. Wiss. Bot.* 46: 55–102.

(23) STOKLASA, J., AND ERNEST, A. 1905 Ueber den Ursprung, die Menge und die Bedeutung des Kohlendioxyds im Boden. *Centbl. Bakt.* (II) 14: 723–736.

(24) STOKLASA, J. 1906 The solubility of phosphoric acid in sugar-beets. *Bl. Zuckerrubenbau* 13: 1–9; 2: 17–25. Abs. in *Exp. Sta. Rec.* 17: 1140.

(25) TRUOG, E. 1912 Factors influencing the availability of rock phosphates. Wis. Agr. Exp. Sta. Res. Bul. 20.

(26) TRUOG, E. 1916 The utilization of phosphates by agricultural crops including a new theory regarding the feeding power of plants. Wis. Agr. Exp. Sta. Res. Bul. 41.

(27) TURPIN, H. W. 1920 The carbon dioxide of the soil air. N. Y. (Cornell) Agr. Exp. Sta. Mem. 32.

THE INFLUENCE OF HEAVY APPLICATIONS OF DRY ORGANIC MATTER ON CROP YIELDS AND ON THE NITRATE CONTENT OF THE SOIL[1]

A. W. BLAIR AND A. L. PRINCE

New Jersey Agricultural Experiment Station

Received for publication December 5, 1927

Attention frequently has been called to the fact that very often heavy applications of dry organic matter, such as straw, have a depressing effect on the crop yield (1, 2, 4, 5, 6, 7, 8, 9). Various explanations have been given. The explanation now most generally accepted is that the crop under such treatment suffers for the lack of available nitrogen. It is claimed that the increase in soil organic matter causes a rapid increase in soil microörganisms and that these actually compete with the growing crop for the supply of available nitrogen. Since the straw furnishes but little available nitrogen there is not enough for both.

Assuming the correctness of this view, it would seem reasonable to expect that properly inoculated legume crops or non-legume crops which have received an abundant supply of available nitrogen, should not suffer in the presence of excessive amounts of straw, as do non-legume crops which have only a limited supply of available nitrogen.

Pot experiments conducted at this station some years ago (3) gave positive evidence that heavy applications of dry organic matter, such as starch, cellulose, dry leaves, and straw, did very seriously interfere with germination and growth of barley and similar crops. At that time, however, parallel work with legume crops was not undertaken. Therefore, it seemed worthwhile to conduct a cylinder experiment in which both legumes and non-legumes should be grown in soil without addition of organic matter and also with varying amounts of dry organic matter.

For this purpose 40 cylinders of the type used at this station were prepared in 1924 and filled with 175 pounds of moist ($13\frac{3}{4}$ per cent water) Sassafras loam soil. The cylinders were arranged in four series of ten each and each series was set off in five pairs so that the work could be carried on in duplicate.

For each series the following treatments were provided:

Two cylinders with no organic matter
Two cylinders with dry rye straw (cut fine) at the rate of 1 ton per acre
Two cylinders with dry rye straw at the rate of 2 tons per acre
Two cylinders with dry rye straw at the rate of 4 tons per acre
Two cylinders with dry rye straw at the rate of 8 tons per acre

[1] Paper of the Journal Series New Jersey Agricultural Experiment Station. Department of Soil Chemistry and Bacteriology.

The straw was worked into the soil to a depth of 4 or 5 inches just before the crops were planted. All cylinders received 20 gm. of acid phosphate (640 pounds per acre), 10 gm. of muriate of potash, and 125 gm. of pulverized limestone (the pH of the original soil was 6.5). Ten of the cylinders were planted to corn, 10 to barley, and 20 to soybeans. For the corn, barley, and half the soybeans, 10 gm. of nitrate of soda was applied to each cylinder. The remaining 10 soybean cylinders received no nitrogen. With some slight modifications, described later, the work was continued through the seasons of 1925 and 1926.

Notes made during the growing period of 1924 show that with 4 and 8 tons of straw there was a distinct depression in both germination and growth of the corn and barley. Germination in these cylinders was little better than 20 per cent of that in the check cylinders, and the barley in these cylinders came to head some time later than that in the cylinders with a small amount of organic matter or no additional organic matter. The corn that received the 4- and 8-ton application of straw likewise showed a need of available nitrogen. The differences mentioned above are clearly brought out in figures 1 to 3.

In the case of the soybeans there was some increase in yield with the 1 and 2 tons of straw as compared with the check, a slight depression with 4 tons, and again some increase with 8 tons of straw. In this case it can hardly be said that the organic matter had a depressing effect on the yield. With one exception, the soybeans treated with nitrate of soda gave larger yields than those without nitrate.

The yields of soybeans, barley, and corn, as measured by the total nitrogen returned in these crops, are shown in table 1. From this it will be noted that in the case of the barley and corn there is a gradual decrease in the amount of nitrogen with an increase of straw. This is not true in the case of the soybeans.

On July 1, nitrates were distinctly higher in the soil from the check cylinders with barley than in the soil from the corresponding cylinders treated with straw (table 2). On the same date the check cylinders with soybeans also showed a higher nitrate content than the straw-treated cylinders. On August 1 and September 1, the check cylinders with corn showed a slightly higher nitrate content than the straw-treated cylinders. On August 1 and September 1, the check cylinders with corn showed a slightly higher nitrate content than the straw-treated cylinders. The figures for barley on September 29 and for soybeans on August 1 and September 29 are fairly constant, the barley soil (after harvest) showing close to 1.4 p.p.m. and the soybean soil about 0.5 p.p.m.

From these figures it is very evident that the growing crops were utilizing the nitrates almost to the limit. This makes it more difficult to determine the extent to which the straw influenced nitrate formation.

In 1925 the experiment was continued, using the same crops and the same fertilizer treatment but without additional rye straw. An examination of the soil at the time of planting indicated that the straw which was applied the

previous season had become thoroughly decomposed. At this time there was no apparent injury where the heavy applications of rye straw had been made. Indeed the crops were slightly better on these cylinders than on the check cylinders. This is clearly shown by figures given in table 3. This would seem to be a confirmation of the belief that the injurious effect of rye straw or other dry organic matter is temporary rather than permanent.

Nitrate determinations were made on samples of soil from the barley and corn cylinders in July, 1925, with results as shown in table 4. These figures

TABLE 1

Total nitrogen returned through crops with and without straw—1924

CYLINDER NUMBER	TREATMENT	SOYBEANS*		BARLEY		CORN
		Series 1	Series 2	Grain	Straw	Forage
		gm.	*gm.*	*gm.*	*gm.*	*gm.*
1 and 2	Check	4.66	4.60	1.18	0.48	1.10
3 and 4	1 ton straw	5.84	6.70	1.16	0.38	1.18
5 and 6	2 tons straw	5.54	6.91	0.99	0.34	1.03
7 and 8	4 tons straw	3.69	4.41	0.56	0.25	0.82
9 and 10	8 tons straw	4.79	6.25	0.33	0.19	0.81

* Series 1 received no nitrogen; series 2 and corn and barley received nitrate of soda—10 gm. per cylinder (320 pounds per acre).

TABLE 2

Parts per million of nitrogen (as nitrates) in soil at different dates during season—1924

NUMBER	TREATMENT	BARLEY	CORN	CORN	BARLEY	SOYBEANS†		
		July 1	August 1	September 29	September 29*	July 1	August 1	September 29
1	Check	1.22	0.56	0.75	1.28	0.70	0.50	0.48
2	1 ton straw	0.69	0.45	0.58	1.48	0.44	0.45	0.45
3	2 tons straw	0.60	0.53	0.56	1.44	0.56	0.54	0.42
4	4 tons straw	0.96	0.42	0.59	1.40	0.46	0.46	0.51
5	8 tons straw	0.64	0.45	0.56	1.48	0.51	0.53	0.45

* Barley was harvested August 9.

† No nitrogen applied for soybeans. Corn and barley received 10 gm. nitrate of soda per cylinder at time of planting.

indicate that here also the crops were using the available nitrogen almost to the limit, the average in each case being less than one part per million. There is no indication that the presence of the straw had any particular influence on the nitrate content of the soil.

SEASON OF 1926

In the spring of 1926 these cylinders were again prepared for planting and rye straw and mineral fertilizers applied as in 1924. The two series that had

TABLE 3

Total nitrogen returned through crops without and with straw treatment—1925

CYLINDER NUMBER	TREATMENT	SOYBEANS*		BARLEY	CORN
		Series 1	Series 2		
		gm.	*gm.*	*gm.*	*gm.*
1 and 2	Check	1.45	2.79	0.93	1.02
3 and 4	1 ton straw	2.18	2.90	0.96	1.28
5 and 6	2 tons straw	2.56	3.25	1.18	1.08
7 and 8	4 tons straw	1.81	2.90	1.24	1.18
9 and 10	8 tons straw	2.90	3.54	1.38	1.39

* Series 1—no nitrogen applied. Series 2—nitrogen as nitrate of soda. For barley and corn, nitrogen as in series 2.

TABLE 4

Parts per million of nitrogen (as nitrates) in the soil, July 1, 1925

CYLINDER NUMBER	TREATMENT	BARLEY	CORN
1 and 2	Check	1.00	0.80
3 and 4	1 ton straw	0.80	0.92
5 and 6	2 tons straw	0.80	0.72
7 and 8	4 tons straw	1.04	0.64
9 and 8	8 tons straw	0.90	1.10

TABLE 5

Total nitrogen returned through crops without and with straw treatment—1926

CYLINDER NUMBER	TREATMENT		CORN*		BARLEY	CORN
	Straw applied	Nitrogen applied as	Series 1	Series 2		
			gm.	*gm.*	*gm.*	*gm.*
1	Check	Nitrate	3.79	3.89	1.10	1.91
2		Urea	3.18	4.03	1.39	2.13
3	1 ton straw	Nitrate	4.01	4.12	1.11	1.84
4		Urea	3.79	3.78	1.00	2.17
5	2 tons straw	Nitrate	4.89	4.70	1.02	1.67
6		Urea	3.12	3.60	1.14	1.71
7	4 tons straw	Nitrate	3.45	4.59	0.80	1.70
8		Urea	3.15	3.65	0.79	1.56
9	8 tons straw	Nitrate	3.85	4.83	0.81	2.03
10		Urea	3.23	3.92	0.65	1.79

* These cylinders received nitrogen equivalent to 20 gm. $NaNO_3$ (640 pounds to the acre) at time of planting and this application was repeated July 29. The odd numbers received nitrate of soda and the even numbers urea nitrogen. The barley and remaining corn received nitrate of soda; the former 10 gm. only, and the latter 20 gm. in two applications.

previously been planted to soybeans were this year planted to corn (for forage) with an extra heavy application of nitrogenous fertilizer as indicated in table 5. The other two series were planted to barley and corn as in 1924. The former received 10 gm. of nitrate of soda per cylinder and the latter 20 gm. in two applications.

The crop yields as measured by the total nitrogen returned in the crops are shown in table 5. From these figures it will be noted that the straw had little effect on the corn that received the heavy applications of the nitrogenous fertilizers. The corn in these cylinders grew luxuriantly and apparently there was enough available nitrogen for the crop and also for the soil microorganisms. With the barley, however, there was a tendency for the yield to decrease as the organic matter was increased. However, this tendency was not so pronounced as in 1924.

Nitrate determinations made on samples of soil taken from the heavily fertilized corn cylinders near the end of August show less than one part of nitrogen per million for a majority of the cylinders. In two instances the nitrates ran as high as four parts per million. The results give no indication that the organic matter influenced the nitrate content of the soil. Also there was little difference between the nitrate content of samples from the nitrate-treated cylinders and the urea-treated cylinders.

Each year for the three years, pH determinations were made on a number of samples from these cylinders including the check cylinders and those with the heavy applications of straw, and although these vary slightly (about pH 6.4 or 6.5 to a little over 7.0), they do not indicate any direct relationship between the amount of organic matter applied and the pH values.

CONCLUSION

In an effort to determine the cause of the depressing effect, on germination and growth, which is often noted when dry organic matter such as straw is applied to the soil preceding the planting of crops, cylinder experiments were conducted on Sassafras loam soil for a period of three years.

Rye straw was used in amounts from 2000 to 16,000 pounds per acre.

Both legume and non-legume crops were grown.

In addition to the rye straw, mineral fertilizers were used and sufficient lime was applied to bring the reaction to a pH varying from about 6.4 to a little above 7.0.

With non-legume crops, receiving a moderate application of available nitrogenous fertilizer, the heavy application of organic matter greatly depressed germination and yield the first year. With the legume crop, both with and without nitrogenous fertilizer, the yields were not appreciably less with the heavy applications of straw than the yields on the check cylinders.

Nitrate determinations made on samples of soil during the summer indicate that the straw did not greatly influence the nitrate content of the soil.

The work was repeated the second year without further addition of organic

matter. This time the non-legume crops in the cylinders which had received the heaviest application of rye straw the year before, gave larger yields than the check cylinders, and again the nitrate content of the soil was not influenced by the organic matter.

The third year only non-legume crops were grown but in this case two sections of corn received an unusually heavy application of nitrogenous fertilizer. The yields, however, were practically the same on the check cylinders as on those that received the heavy application of straw. With barley which received a moderate application of nitrate of soda, the heavy application of straw caused a decrease in yield.

The work furnishes convincing evidence that the depressing effect which is sometimes produced by the application of dry organic matter is due to the locking up of available nitrogen, by organisms which use the organic matter as a source of energy.

REFERENCES

(1) Albrecht, W. A. 1926 Nitrate accumulation in soil as influenced by tillage and straw mulsh. *Jour. Amer. Soc. Agron.* 18: 841–853.

(2) Collison, R. C., and Conn, H. J. 1926 The effect of straw on plant growth. N. Y. Agr. Exp. Sta. Tech. Bul. 114.

(3) Lipman, J. G., and Blair, A. W. 1912 Department of Soil Chemistry and Bacteriology. *N. J. Agr. Exp. Sta. Ann. Rpt.* 1912: 203–277.

(4) Martin, T. L. 1925 Effect of straw on the accumulation of nitrates and crop growth. *Soil Sci.* 20: 159–164.

(5) Murray, T. J. 1921 The effect of straw on the biological processes. *Soil Sci.* 12: 233–59.

(6) Schneidewind, W., Myer, D., and Münter, F. 1911 Investigations on the nitrogen economy of the soil. *Fuhling's Landw. Ztg.* 60: 780–791. Abs. in *Exp. Sta. Rec.* 26: 319.

(7) Scott, Herschel 1921 The influence of wheat straw on the accumulation of nitrates in the soil. *Jour. Amer. Soc. Agron.* 13: 233–258.

(8) Sievers, F. J., and Holtz, H. F. 1927 The maintenance of crop production on semi-arid soil. Wash. Agr. Exp Sta. Pop. Bul. 138.

(9) Stutzer, A. 1907 Investigations on the action of heavy applications of ammonium sulfate in the presence of organic substances and calcium carbonate in the soil. *Jour. Landw.* 55: 81–91. Abs. in *Exp. Sta. Rec.* 19: 220.

PLATE 1

Fig. 1

No. 2, barley without straw; weight of grain 68 gm.
No. 10, barley with straw at the rate of 16,000 pounds per acre; weight of grain 15.6 gm.

Fig. 2

No. 134, soybeans with straw at the rate of 2000 pounds per acre; weight 290 gm.
No. 140, soybeans with straw at the rate of 16,000 pounds per acre; weight 249 gm.

Fig. 3

No. 153, corn with straw at the rate of 2000 pounds per acre; weight 305 gm.
No. 159, corn with straw at the rate of 16,000 pounds per acre; weight 162 gm.

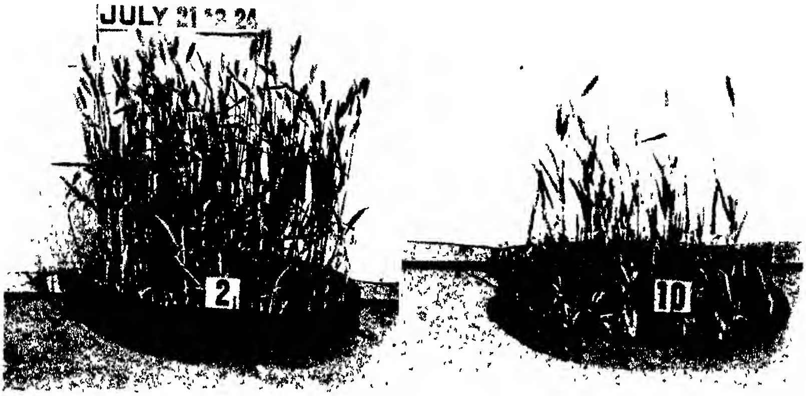


FIG. 1

FIG. 2

FIG. 3

THE ELECTROKINETIC AND CHEMICAL BEHAVIOR OF THE ALUMINO-SILICATES

SANTE MATTSON

Bureau of Soils, U. S. Department of Agriculture

Received for publication December 28, 1927

INTRODUCTION

In earlier publications the author has shown several relationships between the electrokinetic behavior and other properties of soil colloidal materials (9). These investigations have also been applied to a study of artificial alumino-silicates in the belief that information might thereby be gained which would explain the conditions governing the formation of the different natural products which result from the weathering of rock materials.

Regarding the constitution of the mineral part of the colloidal soil material, or the form in which the hydrous oxides of silicon, aluminum, and iron exist in the soil, very little is known. From the extensive literature dealing with this subject it appears that most investigators assume the existence of combinations in the form of hydrous silicates. But although some look upon these combinations as definite compounds of the nature of kaolinite and silicates of higher molecular ratio, other investigators look upon them as adsorption compounds of indefinite composition formed by the mutual precipitation of the colloidal oxides of opposite sign of charge (1, 14, 18).

Since the work of the early investigators in the field of colloidal chemistry—Billiter (2), Biltz (3), and others—silica has been known to be electronegative and from the fact that colloidal solutions of the oxides of aluminium and iron as usually prepared by the method of Graham (7) were found to be electropositive, these oxides are generally, but erroneously, dealt with as electropositive materials. These oxides are, in the terminology of Michaelis, ampholytoids, being isoelectric in the absence of electrolytes at a pH of about 7.0. On the acid side they become increasingly electropositive and the oxychloride of aluminum attains a maximum in respect to this character at a pH of about 5.0. In higher hydrogen-ion concentrations their oxychlorides become again less strongly electropositive evidently because of a dissolution of the colloidal complex. This has been determined cataphoretically and also by measuring their electrical neutralizing power against an electronegative soil colloidal suspension.[1] The isoelectric point as well as the magnitude of the charge is further greatly affected by different ions, especially by the more active ions of a high valence. The electropositive character of the sesquioxides

[1] The results of this work will shortly appear in a paper entitled "Cataphoresis and the electrical neutralization of colloidal materials."

is therefore neither general nor a fixed quantity and any deduction based on such inferences might prove misleading.

In recent years some scientists have studied the mutual precipitation of silica and alumina. Splichal (17) found an optimum precipitation in the proportion of one mol of Al_2O_3 to three mols of SiO_2, whereas Schwarz and Walcker (16) found this optimum to be in the proportion of 1 to 6. The latter found the optimal zone of precipitation at a pH of 4.8 to 5.0. When $Na_4Si_3O_8$ was used, the ratio SiO_2/Al_2O_3 in the precipitate was somewhat greater than 2, while Na_2SiO_3 yielded a product with a ratio a little smaller than 2. They conclude therefore that the compound $H_2Si_2O_5$ would give, with alumina, a precipitate with a ratio of 2. The difference in the SiO_2/Al_2O_3 ratio of their products is more likely due to a difference of pH. The compound Na_2SiO_3 contains the highest proportion of alkali which would weaken the positive charge of the alumina and result in a precipitate with a higher proportion of this component. The difference in the proportions of silica and alumina which, according to the above investigators, produced an optimum precipitation was undoubtedly due to a difference in pH. Bradfield (4) prepared a synthetic sol containing SiO_2, Al_2O_3, and Fe_2O_3 in the same proportion as that of a natural gel and compared the properties of the two. His synthetic sol, however, was electropositive whereas his natural suspension was electronegative.

The problem of the mutual precipitation of colloidal materials of opposite sign of charge can, in the author's opinion, be dealt with successfully only by a study of the electrokinetic behavior of the reacting materials under different conditions. In ordinary solution chemistry it is usually not difficult to follow and to determine the endpoint of the reaction, but where the reacting materials are only colloidally dispersed and where reaction takes place only at the surface and in indefinite proportions, it becomes more difficult to determine what happens. Cataphoresis affords a method of great value in dealing with such reactions, especially in the case of systems having an isoelectric point. By means of a modified form (see footnote 1) of the cataphoresis cell constructed by the author (8), the sign of charge and the velocity of electrical migration may be rapidly and fairly accurately determined not only in the case of the individual particles but also in the case of the flocculated aggregates, provided the latter are not allowed to become too large. The isoelectric point therefore can be observed directly or it can be found by interpolation.

In the following experiments the silica-alumina system has been cataphoretically investigated and a number of isoelectric alumino-silicates have been prepared, analyzed, and studied in respect to a few of their properties.

EXPERIMENTAL

ELECTROKINETIC BEHAVIOR OF THE ALUMINUM CHLORIDE—SODIUM SILICATE SYSTEM

Fifty cubic centimeters of a 0.02 N $AlCl_3$ solution ($=0.017$ gm. Al_2O_3) was rapidly mixed with varying proportions of a sodium silicate solution containing

0.077 gm. SiO_2 in 100 cc. The precipitation which occurred in a certain zone and the turbidity or opalescence which appeared on either side of this zone were noted and the velocities of electrical migration of the aggregates were measured in terms of microns per second in a potential gradient of one volt per centimeter. In the case of the mixtures which remained clear or which developed only an opalescence no particles could be seen in the ultramicroscope. To these mixtures a few drops of a suspension of quartz flour was added. The speed of electrical migration of the quartz particles may be assumed to be about the same as that of the invisible particles in the same medium. The results are given in table 1.

Although precipitation extends over a wide zone, the isoelectric point is approached rather abruptly at a concentration ratio of 1 mol of alumina to 7.4 mols of silica. The pH of the supernatant liquid of the isoelectric precipitate was found potentiometrically to be 4.9. In an experiment conducted three years earlier (1923) with different samples of the same materials the concentration ratio at the isoelectric point was found to be 1 mol alumina to 7.53 mols silica at a pH of 5.0 determined colorimetrically.

TABLE 1

The formation and cataphoresis of the precipitates in aluminium chloride-sodium silicate mixtures

ALUMINIUM CHLORIDE 0.02 N	SODIUM SILICATE	CONCENTRATION RATIO SiO_2/Al_2O_3	APPEARANCE OF MIXTURE	CATAPHORESIS $\frac{\mu}{\text{SEC.}}\ \frac{1\text{ VOLT}}{\text{CM.}}$
cc	cc.			
50	50	3.84	Clear	+ 3.1
50	75	5.74	Opalescence	+ 2.2
50	85	6.53	Precipitated in 18 hours	+ 1.9
50	90	6.91	Precipitated in 5 minutes	+ 1.2
50	95	7.28	Precipitated at once	+ 0.4
50	96	7.37	Precipitated at once	+ slight
50	96.5	7.40	Precipitated at once	± 0 0
50	97	7.44	Precipitated at once	− slight
50	100	7.67	Opalescence	− 1.5
50	125	9.58	Clear	− 5.4
50	150	11.50	Clear	− 5.4

It will be seen that the dispersion of the material increases on both sides of the isoelectric point resulting finally in a high plus and minus charge in apparently clear solutions. These solutions, however, showed a plain Tyndal effect. The maximum negative charge is considerably greater than the maximum positive charge. This is probably due to the fact that with a large excess of the silicate solution the mixture is alkaline and under this condition both of the component oxides are electronegative.

In order further to study the behavior of the different mixtures, large quantities of the following proportions were prepared:

1. An electropositive sol made from 50 parts of each of the two stock solutions and containing 1 mol Al_2O_3 to 3.84 mols SiO_2. 2. An isoelectric mixture of 50 parts of the $AlCl_3$ solution and 96.5 parts of the silicate solution, making an SiO_2/Al_2O_3 ratio of 7.40. 3. An electronegative sol made from 50 parts of the $AlCl_3$ solution and 150 parts of the silicate solution, SiO_2/Al_2O_3 = 11.50 (compare table 1).

In the following, these mixtures will be referred to as the electropositive, the isoelectric, and the electronegative mixture, respectively.

The electropositive mixture (sol)

Increasing quantities of $Ca(OH)_2$ and NaOH were added to 50-cc. portions of the electropositive mixture. The pH was determined colorimetrically

TABLE 2

The influence of $Ca(OH)_2$ and NaOH on the electropositive sol

(SiO_2/Al_2O_3 ratio = 3.84)

pH	PRECIPITATION	CATAPHORESIS $\frac{\mu}{\text{SEC.}}$ $\frac{1\text{ VOLT}}{\text{CM.}}$
	$Ca(OH)_2$	
4.9	Turbid	+ 4.2
5.2	Precipitated at once	+ 2.3
5.6	Precipitated at once	+ 1.3
6.2	Precipitated at once	− 0.7
7.0	Precipitated rapidly	− 2.0
8.2	Precipitated rapidly	− 3.8
	NaOH	
4.8	None	+ 4.3
5.0	None	+ 3.1
5.6	Precipitated at once	+ 1.1
6.2	Precipitated at once	− 0.6
7.0	None	− 3.8
8.2	None	− 4.0

and the state of aggregation and the cataphoretic movement were observed. The results are given in table 2.

The effect of the two bases is in general the same. The wider zone of precipitation and the weaker negative charge produced by the $Ca(OH)_2$ are in harmony with the valence of the cations. It is interesting to note that the positive charge increases in the first stage of alkalization. The migration velocity observed in the case of the original sol was -3.1 μ/sec. (compare table 1). Instead of being isoelectric at a pH of 4.9, as was the case with the mixture having a ratio of SiO_2/Al_2O_3 = 7.40, this mixture, which has a much larger proportion of alumina, becomes more strongly electropositive, a fact accounted for by the formation of the maximum quantity of the electropositive

oxychloride at this stage of alkalization. As the alkalization proceeds the electropositive character of the alumina becomes feebler until a point is reached where there is an electrical balance between the positive and negative components and the system is isoelectric. It is for this reason that a system like the above, which contains a relatively high proportion of alumina, becomes isoelectric only at a comparatively high pH. Every proportion of alumina and silica must have an isoelectric point, each at a definite pH, provided the proportion of silica does not exceed a certain value determined by that quantity which the alumina, at the pH of maximum activity, is able electrically to neutralize. Systems having a higher proportion of silica cannot be isoelectric at any pH but must remain electronegative. To the proportion of alumina there is no limit since this material is itself an ampholytoid.

The electropositive sol is rendered isoelectric not only by a partial alkalization. The addition of a very small quantity of a polyvalent anion such as the ferrocyanide ion brings about a change in the sign of charge without an appreciable change in the pH. Table 3 shows the effect of $K_4Fe(CN)_6$ on the charge and stability of the sol.

TABLE 3

Effect of $K_4Fe(CN)_6$ on the charge and stability of the sol

$K_4Fe(CN)_6$	PRECIPITATION	CATAPHORESIS $\frac{\mu}{\text{SEC.}} \frac{1 \text{ VOLT}}{\text{CM.}}$
milliequiv per liter		
0.1	Gradual	+ 1.0
0.2	Rapid	+ 0.1
0.4	Gradual	− 1.3
1 0	Incomplete	− 2.7
2.0	Slight	− 2.9

The most striking fact of this experiment is perhaps the quantity of the anions which is able to render the sol isoelectric. The sol contained 10 milliequivalents of aluminum, yet as little as 0.2 milliequivalent of the ferrocyanide was almost sufficient to neutralize the positive charge.

The electronegative mixture (sol)

Portions of this mixture were treated with HCl and $Ca(OH)_2$. The effect on the stability of the sol and on the cataphoretic movement is shown in table 4. In the case of the acid treatment the pH values are the most important factors and are therefore given while in the case of the $Ca(OH)_2$ treatment effect is due to the Ca ions, the concentrations of which are given.

The acid treatment reduced the negative charge to a minimum at a pH somewhere below 4.8 but did not change the sign of charge. A mixture with the

above high proportion of silica, therefore, can not be isoelectric. The minimum charge must correspond to the point of maximum electropositive activity of the alumina.

The $Ca(OH)_2$ reduced gradually the negative charge and produced instant precipitation at a migration velocity of 2.4μ. This action of the $Ca(OH)_2$ is different in nature to its action on the electropositive sol (compare table 2). There it acted as a base, reducing by alkalization the positive charge of the alumina, here it acts by virtue of its divalent cation, which reduces the negative charge.

It will be noted that the acid-treated sol precipitates incompletely at a

TABLE 4

The influence of HCl and $Ca(OH)_2$ on the electronegative sol

(SiO_2/Al_2O_3 = 11.5)

pH	PRECIPITATION	CATAPHORESIS $\frac{\mu}{\text{sec.}}$ $\frac{1 \text{ volt}}{\text{cm.}}$
	HCl	
8.2	None	− 5.4
6.9	None	− 5.0
5.4	None	− 4.5
4.8	None	− 2.7
4.4	Incomplete	− 0.8
3.0	None	− 1.8
	$Ca(OH)_2$	
milliequiv. per liter		
0.84	None	− 4.8
1.68	None	− 3.6
2.52	None	− 3.0
3.36	Gradual	− 2.8
4.20	At once	− 2.4

much lower charge than that at which the $Ca(OH)_2$-treated sol precipitates completely. This phenomenon is very often met with and it can be put down as a general rule that: *the more strongly adsorbed the anion, the higher the charge at which an electronegative sol is precipitated by a cation.* For an explanation of this behavior, the author will refer here merely to his theory of ionic linkage (8).

The isoelectric mixture (coagulum)

Table 5 shows the effect of changing the pH in the isoelectric mixture by the addition of HCl and NaOH.

The isoelectric precipitate becomes electropositive with a decrease in pH,

and electronegative with an increase in this value. It is therefore an ampholytoid. In this connection it should be mentioned that a sample of kaolin showed the same cataphoretic behavior. In an aqueous suspension having a pH of 5.5 the kaolin particles migrated toward the anode with a velocity of 1.1μ. When acidified with HCl to a pH of 4.0 the migration was cathodic with an average velocity of 0.7μ per second. The isoelectric point, however, could not be determined with any degree of exactness because the particles did not move with the same speed and did not become isoelectric at the same pH. Another difficulty was due to their large size, which caused them to sink rapidly and disappear from the field of vision.

TABLE 5

Effect of changing pH in the isoelectric mixture

(SiO_2/Al_2O_3 = 7.40)

pH	DISPERSION	CATAPHORESIS $\frac{\mu}{\text{SEC.}} \frac{1\text{ VOLT}}{\text{CM}}$
	HCl added	
4.0	Redispersed	+ 1.5
4.4	Redispersed partly	+ 1.2
4.6	None	+ 0.9
	NaOH added	
5.2	None	− 0.5
5.8	Redispersed partly	− 2.6
7.0	Redispersed	− 4.7

INFLUENCE OF THE pH ON THE ISOELECTRIC POINT OF SILICA-ALUMINA SYSTEMS AND THE COMPOSITION OF THE PRECIPITATES

It has been shown above that different concentration ratios of silica and alumina form isoelectric precipitates at certain hydrogen-ion concentrations provided the proportion of silica does not exceed a certain value. In order to study this relationship between the concentration ratio and the pH and to determine the composition of the precipitates the following work was performed.

A series of mixtures were prepared by mixing 500-cc. portions of an aluminum chloride solution containing 2 millimols (in one case 1.666 millimols) Al_2O_3 with 500-cc. portions of sodium silicate solution containing SiO_2 in the ratios of 1.0, 2.0, 6.0, 7.4, 8.0, and 10.0 mols to each mol of Al_2O_3. Sodium hydroxide was then added to the electropositive mixtures having a ratio below 7.4, and HCl was added to the electronegative mixtures having a larger ratio. The hydroxide and acid solutions were run into the mixtures until a precipitate began to form. They were then added in small portions, the cataphoretic

movement being observed between each addition. Isoelectric precipitates were thus obtained in all but two cases. The mixture having a concentration ratio of 8.0 precipitated but remained electronegative, the slowest movement toward the anode being 0.5μ per second. The mixture having a concentration ratio of 10.0 did not even precipitate completely. After the precipitates had settled, 250 cc. of the clear, supernatant liquid and 250 cc. of the bottom liquid containing the precipitate were siphoned off from each mixture and separately analyzed. From the difference in the quantities of silica and alumina found in the two aliquots the SiO_2/Al_2O_3 ratios of the precipitates were calculated. The results are given in table 6.

All of the concentration ratios within certain limits produce isoelectric precipitates at pH values which increase with the proportion of alumina and decrease with the proportion of silica, in the latter case until the quantity of silica becomes too great to be neutralized electrically by the alumina. The

TABLE 6

The relation between the concentration ratio, the isoelectric pH, and the composition ratio of the precipitates of a few silica-alumina systems

CONCENTRATION RATIO $\frac{SiO_2}{Al_2O_3}$	PRECIPITATE ISOELECTRIC AT pH	Al_2O_3 IN		SiO_2 IN		COMPOSITION RATIO $\frac{SiO_2}{Al_2O_3}$
		250 cc. plus precipitate	250 cc. clear liquid	250 cc. plus precipitate	250 cc. clear liquid	
		gm.	*gm.*	*gm.*	*gm.*	
1.0	6.6	0.1960	0.0008	0.0888	0.0039	0.74
2.0	6.3	0.1875	0.0007	0.1740	0.0150	1.44
3.84	6.0	......	......	......	......	1.83*
6.0	5.1	0.1907	0.0006	0.3836	0.1011	2.52
7.4	4.9	0.1665	0.0025	0.3693	0.1111	2.67
8.0	Not isoelectric	0.1821	0.0058	0.5605	0.1172	4.27
10.0	Precipitate incomplete					

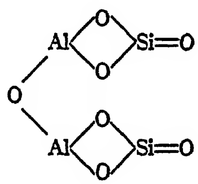
* Analysis of air-dried sample obtained by alkalization with $Ca(OH)_2$ (compare table 2).

compositions of the precipitates show that the SiO_2/Al_2O_3 ratio varies inversely with the pH. This is in accordance chemically with the fact that the higher the pH the more basic the compound formed, and electrokinetically with the fact that the higher the pH the more weakly electropositive the alumina and the less therefore the quantity of silica electrically neutralized.

Practically all of the alumina was removed from the solution above a pH of 5, but appreciable quantities of silica remained in solution even at the higher pH values. This is perhaps very significant because if the precipitates are not chemical compounds but merely the result of a mutual flocculation (if it is permissible to speak about this process as not chemical), why then are the precipitates isoelectric only in the presence of an excess of the electronegative component? None of the precipitates, however, contain silica and alumina in stoichiometric proportions but it will be seen that the SiO_2/Al_2O_3 ratios of all the isoelectric precipitates are smaller than 3. It appears to be as

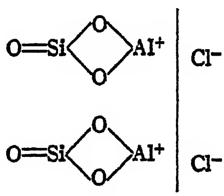
difficult to explain all of these facts on the basis of the formation of definite compounds as it would be to explain them as the results of the mutual flocculation of oppositely charged materials. By all indications both processes are involved.

The electropositive charge of alumina in acid solution is undoubtedly due to the formation of oxycompounds, in this case oxychlorides of the composition Al_2OCl_4, $Al_2O_2Cl_2$, $Al_4O_5Cl_2$, etc., depending on the pH. The colloidally dispersed material dissociates into diffusible Cl ions and positive ion complexes giving rise to an electropositive sol. The magnitude of the charge must increase with the quantity of Cl, hence with a decrease in pH. The weakening of the electrical neutralizing power of an alumina sol observed at low pH values is not due to a decrease in charge but rather to a decrease in the quantity of colloidal material due to an increased solubility. When the oxychlorides are alkalized they become first isoelectric and then electronegative. The fact that kaolin becomes electropositive when acidified with HCl can be explained in the same way. Kaolin is alumina in which two of the oxygen atoms have been displaced by SiO_3 groups thus:



(*A*)

The remaining oxygen atom may be displaced by HCl forming a compound still insoluble but capable of dissociating into Cl ions and an electropositive alumino-silicate complex thus:



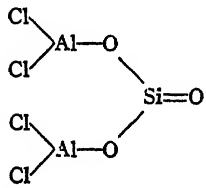
(*B*)

the vertical line representing the separation into an inner and an outer electrical layer.

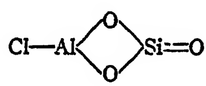
From the above formula (*B*) it is evident that a silicate with an SiO_2/Al_2O_3 ratio of 3, in which all of the alumina oxygen is displaced by silicate radicals can not combine, as such, with HCl and would therefore not possess an ampholytoid character. It is probably for the same reason that all the isoelectric precipitates had a ratio smaller than 3. The same observation has been made in the case of soil colloidal materials. Of a series of such materials examined cataphoretically only those having a low SiO_2/Al_2O_3 ratio became electro-

positive in HCl solutions while the materials in which this ratio was high remained electronegative in all concentrations of the acid (9). Experiments on the adsorption of acids by the different materials then showed that while the materials having a high ratio adsorbed either none or mere traces of HCl, all the materials with a low ratio and which became electropositive adsorbed appreciable quantities of the acid (11).

In view of the fact that a definite compound like kaolinite possesses the same ampholytoid character as the above isoelectric precipitates it is possible that the latter also constitute definite compounds. Since these were all formed in the presence of free HCl at pH values at which the alumina must exist as an oxychloride it is evident that the reactions must have taken place between these oxychlorides and the silica. At the varying hydrogen-ion concentrations the following compounds might be assumed to be formed:

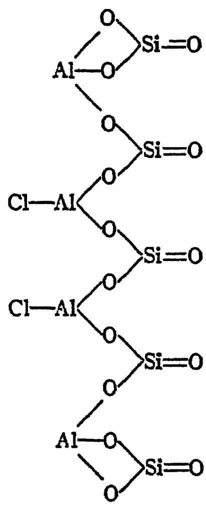


(*C*)



(*D*)

and



(*E*)

having an SiO_2/Al_2O_3 ratio of 1, 2, and 2.5 respectively. These compounds would all be electropositive, forming more or less stable sols but they could be rendered isoelectric and be precipitated by alkalization. They might also be

isoelectrically precipitated by the action of electronegative colloids, such as silica and humus, or by a number of anions, especially by those having a high valence. Where silica is present in excess as in the above experiments a mutual precipitation of the electropositive compounds and silica might be assumed. This would account for the composition ratios being uneven numbers. The assumption would also be in harmony with the fact that to reach an isoelectric point the alkalization had to be carried to a higher pH the lower the proportion of silica.

If definite compounds like those represented by the above formulas were formed one should expect the ratio of silica to alumina to increase with the pH. But the compositions of the isoelectric precipitates show on the contrary that a reversed relationship exists. This indicates that the higher silicates such as the normal $Al_2(SiO_3)_3$ are unstable and are therefore not formed, a condition which would result if the solubility product of the hydroxide of aluminium were lower than that of the silicate. But this does not say that a lower silicate of the composition of kaolinite may not be formed at a somewhat lower pH. This assumption would be in accordance with the composition and behavior of the above precipitates as well as with the conditions under which kaolinite is supposed to be formed in nature. It would also be in agreement with the fact that a high silica content in soil colloidal materials is always associated with a high content of mono- and divalent bases, whereas materials having an SiO_2/Al_2O_3 ratio of 2 or less usually contain very small amounts of these bases, indicating that the alumina alone is able to fix only a limited quantity of silica.

According to Wüst (20) kaolinization is caused by the action of humic acids. This action of the humus might be explained as follows: The humus reduces the pH to a value at which a combination of silica and alumina of the ratio of 2 is formed. The pH values of a number of peats were found by Odén (12) to range about 4. At such acidities the kaolinite would be electropositive and might be expected to precipitate isoelectrically with the strongly electronegative humus instead of as in the above experiments with silica. The precipitate would thereby maintain the kaolinite ratio. The complex would assume with age a coarser structure through crystallization and would become more stable both chemically and colloidally. The humus would gradually be oxidized leaving a deposit of more or less pure kaolinite. The action of humus is accordingly twofold but consists primarily in adjusting the pH to an optimum for the formation of kaolinite. That an acid reaction is essential for the formation of this compound is further emphasized by the views of Rösler (15) who claims that kaolinite is produced by pneumatolytic action, that is, by the operation of thermal waters and gaseous emanations. The only effect of the latter would seem to be due to their acid character.

Evidence that kaolinite is formed from its constituents and that it may, at a certain pH, appear as a cation or at least in the form of an electropositive complex sufficiently dispersed to pass through a parchment was obtained by

an experiment very remote from the above. On subjecting a sample of 100 gm. of powdered feldspar to electrodialysis (10) the cathode dialysate, which was removed at intervals, was clear at the beginning and contained considerable quantities of bases but as the alkalinity later decreased a gelatinous, light colored sediment appeared. At this point the pasty mass of feldspar in the central chamber reacted acid to litmus. In the course of several days a sufficient quantity of this sediment was obtained for an examination. A quantity of 0.3243 gm. of the ignited sediment contained 0.1589 gm. SiO_2 and 0.1549 gm. Al_2O_3 giving an SiO_2/Al_2O_3 ratio of 1.74. The appearance of silica at the cathode can be explained only by assuming the existence of a complex cation in which silica enters as a constituent part. The fact that the sediment did not appear until the feldspar was partly dealkalized by the electric current and had an acid reaction indicates that the hypothetical ion could only be formed or assume mobility in a somewhat acid medium.

The formation of an alumino-silicate ion having a composition represented by formula (*B*) might be theoretically accounted for in the case of either of the feldspars. By the removal of the base and a part of the silica from orthoclase thus:

$$2KAlSi_3O_8 = K_2O + 4\ SiO_2 + Al_2O(SiO_3)_2$$

and from anorthite thus:

$$CaAl_2Si_2O_8 = CaO + Al_2O(SiO_3)_2$$

the basic silicate $Al_2O(SiO_3)_2$ or $AlOHSiO_3$ would be formed. In a faintly acid solution in which this compound would be stable it would yield the complex cation $(AlSiO_3)^{++}$. The fact that the sediment had a ratio of 1.74 instead of 2.0 might be taken to indicate that the ion contained a correspondingly smaller proportion of silica. But it must be remembered that as soon as the ion entered the alkaline solution in the cathode chamber it must have been decomposed, forming, perhaps, alkali silicates and aluminates whose anions would migrate toward the anode. From the conditions of the experiment it is impossible to say, therefore, just what the composition of the ion was when it entered the chamber.

THE INFLUENCE OF ANIONS AND CATIONS ON THE COMPOSITION OF THE ISOELECTRIC PRECIPITATES

It has been shown that an electropositive sol containing 1 mol alumina to 3.84 mols silica could be isoelectrically precipitated by the addition of a little potassium ferrocyanide (table 3). In order to determine the composition of this precipitate a large quantity was prepared by adding sufficient ferrocyanide to render 10 liters of the sol isoelectric. The precipitate was then filtered and washed a few times with distilled water. Half a gram of the air-dried material contained 0.1650 gm. SiO_2 and 0.1763 gm. Al_2O_3, giving an SiO_2/Al_2O_3 ratio

of 1.58. The influence of the tetravalent anion is therefore identical with that of the OH ion, i.e. alkalization. When alkalized with $Ca(OH)_2$ the same sol yielded an isoelectric precipitate with a ratio of 1.83 (compare table 6). Both ions partly neutralize the positive charge of the alumina thus enabling an isoelectric precipitate to form with a smaller proportion of silica, the ferrocyanide ion being in this respect the more active.

In regard to the formation of the alumino-silicate complex under natural conditions the conclusion may be drawn that the ratio of silica to alumina will be reduced by the presence of active anions. The pH is therefore not the only chemical factor which must affect the composition of this complex.

From the work of Robinson and Holmes (14) it is known that the proportions of the mono- and divalent bases in the soil colloidal materials increase with the ratio of silica to alumina. In view of this fact it was desirable to determine the influence of these cations on the composition of the isoelectric precipitates of silica and alumina. Since the Cl ion is electrokinetically the least active among the common anions, the neutral chlorides were employed in the work. It was found that when the chlorides of Ca, Mg, and K were added to the sodium silicate before the latter was mixed with the $AlCl_3$ solution, isoelectric precipitates were formed at about the same pH and in mixtures containing about the same proportion of silica and alumina as when none of these chlorides were added (compare table 1). The above cations, therefore, appeared to have very little influence, if any, upon the isoelectric point. But the composition of the precipitates showed a considerable increase in the proportion of silica as compared to the composition of the precipitate obtained in the absence of these cations.

Large quantities of isoelectric precipitates were prepared from mixtures of the following proportions:

(*a*) 1 mol Al_2O_3 + 7.4 mols SiO_2; isoelectrically precipitated at pH 4.9.
(*b*) 1 mol Al_2O_3 + 7.46 mols SiO_2 + 1.5 equivalents $MgCl_2$; isoelectrically precipitated at pH 5.0.
(*c*) 1 mol Al_2O_3 + 7.21 mols SiO_2 + 1/3 equivalent of each of the chlorides of Ca, Mg, and K; isoelectrically precipitated at pH 4.7.

The precipitates were washed a few times with water and samples of half a gram of the air-dried materials were then analyzed. The potash was not determined. The results are given in table 7.

The presence of the cations caused a considerable increase in the proportion of silica in the precipitates. The effect of the cations is therefore the opposite to that of the anions. Very little of the cations remained in the precipitates, however, a fact which may be ascribed to the low pH. Isoelectric precipitates obtained at higher pH values in the presence of Ca and Mg showed a higher proportion of these cations, although the proportion of silica decreased, as has been shown.

It will be seen that the precipitate formed in the absence of neutral chlorides

shows a ratio of 2.26 while the precipitate in table 6, which was obtained under the same conditions, had a ratio of 2.67. The latter was determined by the difference in composition between the bottom liquid containing the precipitate and the supernatant liquid. The precipitate in table 7 was washed before analysis and must have lost silica during this process, which is easily explained. The washing with distilled water increased the pH and thereby rendered the material electronegative, as verified by cataphoresis. It has further been shown that the higher the pH the smaller the proportion of silica with which the alumina is able to combine. It is therefore evident that the increase in pH caused some of the silica to be released.

TABLE 7

The influence of cations on the composition of isoelectric precipitates of alumina and silica

PRECIPITATED IN PRESENCE OF	COMPOSITION OF PRECIPITATES				
	SiO_2	Al_2O_3	CaO	MgO	SiO_2/Al_2O_3
	gm.	*gm.*	*gm.*	*gm.*	
....	0.2206	0.1661	......	......	2.26
$MgCl_2$..........................	0.2297	0.1267	......	0.0071	3.07
$CaCl_2$, $MgCl_2$, KCl................	0.2558	0.1275	0.0007	0.0026	3.40

The above observations may be summarized as follows:

1. The alumina-silica system forms isoelectric precipitates in which the proportion of silica decreases with an increase in pH, approaching zero at pH 7.0 at which the alumina is itself isoelectric.

2. In the presence of active anions the alumina-silica system forms isoelectric precipitates in which the proportion of silica is lower than this proportion in the precipitates which are formed at the same pH but in the absence of such anions.

3. In the presence of cations the proportion of silica in the isoelectric precipitates is correspondingly increased.

By the addition of the hydroxides of Ca and Mg, precipitates of alumina and silica may be produced in which the proportion of silica has no limits but such precipitates are always electronegative. On precipitating the electronegative sol with $Ca(OH)_2$ (table 4) an SiO_2/Al_2O_3 ratio of 5.65 was found. This precipitate contained large quantities of Ca which was easily removed by leaching with NH_4Cl solution. When the same sol was precipitated with magnesia mixture a material having an SiO_2/Al_2O_3 ratio of 8.27 was obtained. This precipitate contained large quantities of Mg. After prolonged leaching with normal NH_4Cl solution it still retained 1.856 milliequivalents per gram (3.71 per cent MgO). In this connection it might be pointed out that natural soil colloidal materials with a high proportion of silica and which are always electronegative (acidoids) contain in general large quantities of Ca and Mg. A large part of the Ca is subject to base exchange, whereas usually only a small proportion of the Mg is exchangeable.

According to Robinson and Holmes (14) soil colloidal materials containing a high proportion of silica and mono- and divalent bases are usually found only in regions of low rainfall, that is, in regions where the leaching is reduced to a minimum and where the silica and the bases, which otherwise are the first products of hydrolysis to be leached out, accumulate together with the sesquioxides. The gel which precipitates out under such conditions must be electronegative and contain a high proportion of silica and bases.

In regions of heavy rainfall the bases set free during the process of rock weathering are leached out to a very great extent. It has been shown above that in the absence of precipitating ions a gel can be formed only at or near the isoelectric pH of any given proportion of alumina and silica. The composition of the gel which is formed in an extensively leached soil will depend, therefore, on the pH. In tropical countries of periodic, heavy rainfall the pH will, in spite of the leaching, be kept fairly high because of an intensified hydrolysis resulting from a high temperature, and also because of the rapid decomposition of the organic matter, preventing an accumulation of an acidifying layer of humus as in colder countries. The gel which precipitates out under these conditions—that is, at a high pH and in the absence of appreciable quantities of bases—must contain a very low proportion of silica and possess an ampholytoid character. At a pH near 7.0 and in the practical absence of bases the gel would consist of almost pure sesquioxides. Although these are the conditions which must favor laterization they do not account for the upward movement of the iron oxide. To explain this movement of the iron would require a thorough study of the iron oxide-silica system. This has not yet been done but preliminary experiments indicate that iron oxide behaves in general like alumina with the difference that the zones of precipitation of the iron oxide-silica system are much more narrow, indicating that the silica protects the iron oxide more effectively than it protects the alumina. The upward movement of the iron oxide in dry periods as explained by Ehrenberg (5) may be due to this protective action of the silica, permitting under certain conditions a high degree of dispersion of the iron oxide. In the upper soil horizons the sol would be precipitated by the higher ion concentration as explained by Ehrenberg.

In colder countries with heavy rainfall the reaction of the soil solution will, in the absence of carbonates, be more acid because of the slower weathering and the accumulation of humus. The composition of the silicate gel which precipitates under such conditions must contain an intermediate proportion of silica, for although the bases together with silica are extensively removed by leaching a certain proportion of the latter will be precipitated by the alumina. The proportion of silica thus precipitated should increase, within certain limits, with an increase in acidity. But in the absence of appreciable quantities of bases the proportion of silica to alumina in the natural (as in the artificial) gel will probably never be found to attain a ratio of 3.

The above three conditions of gel formation may be expressed in a general statement as follows:

1. In the presence of appreciable quantities of bases a silicate gel containing a high proportion of silica and bases will be precipitated.
2. In the absence of appreciable quantities of bases but at a reaction about neutrality the gel which precipitates will consist chiefly of sesquioxides.
3. In the absence of appreciable quantities of bases and at an acid reaction the precipitating gel will contain an intermediate proportion of silica.

A silicate gel containing a high proportion of bases and therefore also a high proportion of silica must, upon the removal of the bases by leaching, lose as much of its silica as is in excess of that proportion which the sesquioxides at the prevailing pH are able electrically to neutralize. This was indicated by an experiment with the Sharkey soil colloidal material. This material (SiO_2/Al_2O_3 = 3.18) contained 0.71 milliequivalents exchangeable bases per gram which were removed by electrodialysis (10). One gram of the electrodialyzed material was placed in 1 liter of water on the steambath for 2 weeks. The suspension was then filtered and the filtrate analyzed and found to contain 0.0247 gm. SiO_2 and 0.0022 gm. sesquioxide. The material with bases unsaturated was therefore unstable with respect to its silica content. The exchange capacity (determined by saturating with $CaCl_2$ and displacing with NH_4Cl) of the water-treated material was found to be 0.607 milliequivalent per gram as compared to 0.692 milliequivalent per gram of the same material which had been kept dry. The loss in silica was accompanied therefore by a loss in the power to adsorb and exchange bases, which is in harmony with the previous observations of the author.

THE RELATIONSHIP BETWEEN THE BASE EXCHANGE CAPACITY AND THE SiO_2/Al_2O_3 RATIO

The author previously has shown that the base exchange capacity of soil colloidal materials varies with the ratio of silica to alumina (9). Since the electrokinetic behavior of the artificial products is very similar to that of the natural and since the ratio of silica to alumina is of the same order of magnitude in both, it was a matter of great interest to determine the exchange capacity of the different precipitates.

Of the four isoelectric precipitates used in this work, one was prepared by alkalizing the electropositive sol with $Ca(OH)_2$ (compare table 2) and the three others were prepared according to table 7. One gram of each of the materials, which had been dried on the steambath, were weighed out and placed on the filter. They were then treated with a hot normal solution of $CaCl_2$ until the filtrate in each case indicated a pH of 6.4 with brom thymol blue as indicator. This endpoint was selected because of the slowness with which the point of neutrality was approached. The samples were then washed until the disappearance of the Cl reaction and this was followed by a treatment with 250 cc.

hot, normal NH_4Cl solution which displaced all of the adsorbed Ca. Table 8 gives the quantities of displaced Ca in milliequivalents per initial gram of the materials together with the ratios of silica to alumina before and after the treatment.

TABLE 8

The base exchange capacities of the isoelectric precipitates and their SiO_2/Al_2O_3 ratios

SiO_2/Al_2O_3 RATIO BEFORE TREATMENT	EXCHANGE CAPACITY	SiO_2/Al_2O_3 RATIO AFTER TREATMENT
	milliequiv./gm.	
1.83	0.460	1.78
2.26	0.614	2.22
3.07	0.886	2.96
3.40	0.996	3.30

The base exchange capacities of the artificial alumino-silicates not only increase with the ratio of silica to alumina as do the exchange capacities of the natural soil colloidal materials, but the order of magnitude of the former is the same as that of the latter. From the author's earlier work above referred to the following figures are quoted:

SiO_2/Al_2O_3 ratio of soil colloidal materials..............................	3.82	3.18	2.82	1.89	1.63	0.55
Base exchanged capacities (milliequiv. per gram).........................	0.947	0.796	0.671	0.331	0.207	0.164

The exchange capacities of the artificial materials are in proportion to the ratios of silica to alumina—somewhat higher than those of the natural products. This might be due to a greater internal surface in the case of the freshly precipitated materials.

THE MECHANISM OF BASE EXCHANGE

The above described electronegative precipitate, obtained by precipitating the electronegative sol with $Ca(OH)_2$, which had an SiO_2/Al_2O_3 ratio of 5.65, showed an exchange capacity of 2.307 milliequivalents per gram. (This was determined after all of the Ca originally present had been removed by a preliminary treatment with NH_4Cl and represents therefore only the Ca adsorbed from the $CaCl_2$.) This is equal to 6.46 per cent CaO and shows that the exchange capacity can become very great as the proportion of silica increases. But no one appears to have been able to induce any appreciable exchange capacity in pure silica gel and the power to adsorb and exchange cations is generally assumed to reside in a hypothetical alumino-silicic acid. Even the fact that activated charcoal adsorbs bases is explained with the statement that all charcoals contain oxygen and hydrogen and might therefore contain COOH groups (13).

If the adsorption and exchange of base actually were due to the existence of true acids which react with bases with the elimination of water then the addition of a base should increase the dry weight of the adsorbent by an amount equal to the weight of the added cation minus the weight of the displaced hydrogen, provided, of course, that the degree of hydration of the adsorbent remains the same after drying at the same temperature. Because of the author's previously advanced theory (8) that the adsorption of the cations is due to, and follows the adsorption of, the OH ions the following experiment was performed in order to determine which of these views is correct: Four 1-gm. samples of air-dried, electrodialyzed Sharkey clay colloidal material were accurately weighed out. To each of two of these samples, 0.65 milliequivalent of $Ca(OH)_2$ was added in platinum crucibles. This quantity of base was immediately adsorbed without leaving an alkaline reaction. The

TABLE 9

Loss in weight on drying and on ignition of electrodialysed and Ca-saturated Sharkey soil colloidal material (0.65 milliequivalent $Ca(OH)_2$ added per gram)

TREATMENT	Ca-SATURATED	ELECTRO-DIALYSED	AVERAGE DIFFERENCE	CALCULATED DIFFERENCE ASSUMING OH AND CA ABSORPTION	CALCULATED DIFFERENCE ASSUMING NEUTRALIZATION
	gm.	*gm.*	*gm.*		
Dried at 108°C.	0.9330	0.9064		(0.65 × 0.037) =	
	0.9325	0.9086	0.0242	0.0240	0.0124
Ignited	0.8316	0.8109		(0.65 × 0.028) =	
	0.8321	0.8131	0.0187	0.0182	0.0182
Loss by ignition	0.1014	0.0955		(0.0240 − 0.0182) =	
	0.1004	0.0955	0.0054	0.0058	−0.0058

water was then evaporated under conditions which excluded CO_2. The four samples were dried together in the oven for 24 hours at 108°C., weighed, ignited, and again weighed. The results are given in table 9.

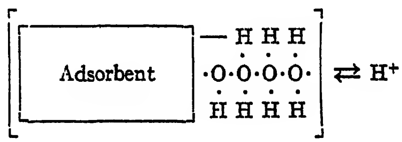
If the adsorption of the base consisted in the neutralization of an acid, then the oven-dried, Ca-saturated samples should weigh 0.0124 gm. (0.65 milliequivalent Ca minus 0.65 milliequivalent H) more than the unsaturated samples. On ignition the unsaturated material must, if an acid, be converted into the corresponding anhydride and therefore must not only lose that part of the volatile matter which is common to all the samples, but an additional quantity of water, equivalent to the Ca adsorbed by the Ca-saturated samples. The difference in weight between the ignited, Ca-saturated and the unsaturated samples should therefore be 0.0182 gm. (0.65 milliequivalent CaO) and the loss on ignition of the unsaturated samples should be greater than that of the Ca-saturated samples. If, as assumed by the author, both of the ions are

adsorbed, then the difference in weight of the dried samples should equal the weight of 0.65 milliequivalent of $Ca(OH)_2$ or 0.0240 gm. On ignition the Ca-saturated material should lose, in addition to that quantity of volatile matter which is common to all the samples, a quantity of water represented by the conversion of 0.65 milliequivalent of the hydroxide into CaO. The difference in weight between the ignited, Ca-saturated and the unsaturated samples should be equal to the weight of 0.65 milliequivalent CaO, or 0.0182 gm. The loss on ignition of the Ca-saturated samples should be greater, therefore, than that of the unsaturated samples and the difference in loss on ignition of the two samples should be equal to the weight of water lost by converting 0.65 milliequivalent of $Ca(OH)_2$ into CaO, or 0.0058 gm. The results of the experiment show that the difference in weight of the oven-dried samples is almost exactly what it should be if both ions of the base were adsorbed and the difference in the loss on ignition between the Ca-saturated and the unsaturated samples (0.0054 gm.) represents very nearly the loss of converting 0.65 milliequivalent $Ca(OH)_2$ into CaO.

The above experiment therefore speaks strongly in support of the theory that both ions of the base are adsorbed and against the theory of neutralization and the existence of an alumino-silicic acid. The next question is: what is the mechanism of this adsorption? That the anions are adsorbed in excess of the cations is indicated by the electronegative charge and by the increase in this charge by the addition of compounds of weakly adsorbed cations, such as those of the alkalies, to a soil suspension. It may be said that all chemically inert materials charge themselves electronegatively by adsorption of anions in water and in solutions of the common electrolytes. Materials which charge themselves electropositively appear to do so by virtue of a dissociation, and represent special cases. The proteins which are true ampholytes are electropositive in acid solutions. The insoluble oxychlorides of iron and aluminum and other metals dissociate diffusible anions and are therefore electropositive. Barium sulfate and other precipitates may, by virtue of an unequal solution tension of their ions, be either positive or negative. But all of these materials become electronegative by adsorption in solutions of the hydroxides and other compounds of the alkalies.

The fact that the great body of materials, very different in nature, such as the noble metals, charcoal, humus, quartz, and other minerals, charge themselves electronegatively in the same dispersion medium, namely water, is perhaps best explained by a consideration of the nature of that medium itself. Since the electrokinetic potential depends upon the most minute concentrations of ions, water must, for the subject here dealt with, be looked upon as an electrolyte. In the second place, water is an ideal type of ampholyte since by dissociation an equal number of H and OH ions are formed. One of these ions, the OH, has been shown to be one of the most strongly adsorbed ions (8). Now it is generally assumed that the water molecules, or rather groups of associated water molecules arrange themselves in an oriented position at

interfaces, probably because of an inequality in the strength of the electric fields at phase boundaries. This means that adsorbed water is structurally different from ordinary water in which the molecules have a random distribution. The question arises: is the adsorbed water also chemically different from ordinary free water? If groups of associated water molecules are electrical bipoles and if the polar orientation is such that the OH ions are attracted toward the interface then it follows that adsorbed water must be more acidic than water in the free condition. The fixation of the OH ions at the interface leads to the liberation of a proportionally greater number of H ions which, because of electrostatic forces, are held in the form of an outer layer surrounding the adsorbent. This may be represented by the following scheme:



This would account for the sign of charge of the great body of very different materials (acidoids) which in water charge themselves electronegatively. It would also account for the often observed fact that these materials show a higher H-ion concentration at their surface than that of the surrounding solution. Further, since the H ions may be displaced by other cations, the source of the acid liberated by the neutral salt treatment is also accounted for. The adsorption of the ampholyte, water, weakens its basic and strengthens its acidic properties, and adsorbed water exhibits therefore the character of an acid. The attraction of the anions to the interfacial side of the adsorbed layer of water is not restricted to the OH ions of the water but affects more or less all anions. The polyvalent anions together with the OH ions are the most strongly attracted. When a base is added to soil materials the OH ions are directly attracted to the interfacial side of the polarly oriented layer of water molecules and the cations are held by electrostatic forces and form the outer ionic layer. The H ions already present in this layer will to a great extent be displaced by the more numerous metal cations in the solution resulting in the formation of a corresponding quantity of water. When a neutral salt is added the process is the same, the H ions are displaced and in addition a certain quantity of base is adsorbed, resulting in each case in the liberation of free acid. An additional quantity of base is adsorbed because the increased osmotic pressure of the cations relieves the stress which must exist in the form of an outward pull on the OH ions because of the tendency of the cations to diffuse and distribute themselves equally in the solution. The higher the concentration of the cations the more extensive therefore the adsorption of the OH ions. This means that the neutral salts are subject to hydrolysis in the presence of adsorbents which strongly adsorb the OH ions. In the presence of such adsorbents salts of strong bases must behave as do salts of weak bases,

that is, they must be subject to hydrolysis, as the author several years ago pointed out (8).

Although the acidoid behavior of soils and other adsorbents is held to be more directly connected with the structure and properties of the adsorbed layer of water it is evident that this behavior is not independent of the nature and condition of the adsorbents. The latter determine the magnitude and direction of the forces at the phase boundaries and the molecular and ionic linkages established with the dispersion medium must depend upon these forces. Besides the fact that the exchange capacity varies with the ratio of silica to alumina as shown above, another significant observation has been made in the case of soil colloidal materials possessing a very high proportion of sesquioxides such as the laterites. Like the sesquioxides themselves, these materials are electropositive in acid solutions and adsorb and exchange no cations in this condition. In alkaline solutions in which they are electronegative these materials adsorb quantities of bases and exceed in this respect the soil colloidal materials having the highest proportion of silica (11). It would appear, therefore, as if the electropositive condition of the material brings about a different orientation of the interfacial layer of water molecules than that of the acidoid structure.

Whether all of the adsorbed cations remain free in the outer ionic layer as assumed by Wiegner (19) or whether a certain proportion of these ions are attracted to, and associated with, the oppositely charged interfacial layer is another question. The fact that the electrokinetic potential attains a maximum long before a soil is saturated with NaOH and that the potential is reduced at the outset by the addition of $Ca(OH)_2$ may be explained on the basis of either viewpoint. The electrokinetic potential is directly proportional to the distance between the inner and outer ionic layers (6). If now, as maintained by Wiegner, the highly hydrated Na ions remain at a greater distance from the inner layer than the less hydrated divalent Ca ions, then the observed difference in electrical migration produced by the two ions is accounted for. The fact that the potential reaches a maximum long before saturation and is reduced with increasing concentrations of the electrolyte would be explained on the assumption that the outer layer is pushed closer to the inner layer by the increased osmotic pressure of the cations. Calculations made by the author (10) show that an absurd low value for the thickness of the double layer has to be assumed if all of the cations that a soil colloidal material is capable of adsorbing exist free in the outer layer. It was considered more probable, therefore, that for each ion there exists a critical potential above which the ion is attracted to, and associated with, the interfacial layer and that only a comparatively small number of cations remain free in the outer layer. The greater the hydration of the ions the greater will be their tendency to remain free. The above facts are equally well accounted for, however, on the basis of the Donnan equilibrium, according to which an increase in the concentration of the free (unadsorbed or uncombined) ions in the solution as

well as an increase in valence causes a decrease in the potential difference. But even if this theory is used as a basis for the interpretation of the electrokinetic behavior, calculations, to be published later, show that if all of the cations a soil colloidal material is capable of adsorbing, exist free in the form of a swarm in the micellar liquid, a potential difference between this liquid and the outside solution would be established which would be very much greater than any observed.

SUMMARY

On mixing increasing quantities of sodium silicate with an aluminum chloride solution, an electropositive sol, an isoelectric precipitate, and finally (with an excess of silica) an electronegative sol are successively formed. The electropositive sol may be precipitated isoelectrically by alkalization and the electronegative sol by the addition of acid provided that the proportion of silica is not greater than the quantity which the alumina is able electrically to neutralize. Each proportion of silica and alumina forms, within certain limits, isoelectric precipitates at definite H-ion concentrations ranging in pH values from somewhat below 5 to about 7 at which the alumina is itself isoelectric. The nearer a pH of 7 the greater must the proportion of alumina be for an isoelectric precipitation. The molecular ratio SiO_2/Al_2O_3 in the isoelectric precipitates decreases with an increase in pH, approaching zero at a pH of 7. At pH values somewhat below 5 the ratio reaches a maximum but remains always smaller than a ratio of 3. The proportion of alumina in the isoelectric precipitates is increased by the action of polyvalent anions whereas the proportion of silica is increased by the presence of cations. In the latter case isoelectric precipitates may be formed in which the ratio SiO_2/Al_2O_3 considerably exceeds a value of 3. Mixtures containing so much silica as to render the sol electronegative at any pH may be precipitated by adding bases of the divalent cations, but the precipitates, which contain a large proportion of silica and bases, remain electronegative and exhibit no ampholytoid character at any pH. The isoelectric precipitates are, like kaolinite, ampholytoids becoming electropositive when acidified and electronegative when alkalized.

Evidence obtained by the electrodialysis of feldspar indicates that the kaolinite cation $(AlSiO_3)^+$ is stable and may be formed at certain H-ion concentrations. The conditions governing the formation of the different soil gels in nature are discussed in this connection.

The base exchange capacities of the several precipitates prepared were found to increase with the ratio of silica to alumina and to be of the same order of magnitude as those of the natural gels.

The adsorption of base by the natural gel has been shown to embrace the adsorption of both ions, the OH as well as the cation, indicating true adsorption instead of the neutralization of an acid. The mechanism of adsorption and exchange has been discussed. The conclusion has been reached that the acidoid behavior of adsorbents is associated with a polar orientation of the interfacial layer of water molecules.

REFERENCES

(1) Bemmelen, J. M. van 1904 Beiträge zur Kenntnis der Verwitterungsprodukte der Silikate in Ton. *Ztschr. Anorgan. u. Allg. Chem.* 42: 265–314.

(2) Billiter, J. 1905 Theorie der Kolloide II. *Ztschr. Phys. Chem.* 51: 150.

(3) Biltz, W. 1904 Ueber die gegenzeitige Beeinflussung colloidal gelöster Stoffe, *Ber. Deut. Chem. Gesell.* 37: 1095.

(4) Bradfield, R. 1923 The chemical nature of colloidal clay. Univ. of Missouri Res. Bul. 60.

(5) Ehrenberg, P. 1922 Die Bodenkolloide, ed. 3. Dresden und Leipzig.

(6) Freundlich, H. 1922 Kapillarchemie, ed. 2, p. 537. Leipzig.

(7) Graham, Th. 1862 *Liebig's Ann. Chem.* 121: 45. (Freundlich, Kapillarchemie, p. 715.)

(8) Mattson, S. 1922 Die Beziehungen zwischen Ausflockung, Adsorption und Teilchenladung mit besonderer Berücksichtigung der Hydroxylionen. *Kolloidchem. Beihefte.* 14: 227–316.

(9) Mattson, S. 1926 The relation between the electrokinetic behavior and the base exchange capacity of soil colloids. *Jour. Amer. Soc. Agron.* 18: 458–470; 510–513.

(10) Mattson, S. 1926 Electrodialysis of the colloidal soil material and the exchangeable bases. *Jour. Agr. Res.* 33: 553–567.

(11) Mattson, S. 1927 Anionic and cationic adsorption by soil colloidal materials of varying $SiO_2/Al_2O_3 + Fe_2O_3$ Ratios. *Proc. First Internatl. Cong. of Soil Sci.*, Comm. II.

(12) Oden, S. 1919 Die Huminsäuren, p. 154, Dresden u. Leipzig.

(13) Page, H. J. 1927 Transactions of the Second Commission of the International Society of Soil Science, Groningen. v. B, p. 44.

(14) Robinson, W. O., and Holmes, R. S. 1924 The chemical composition of soil colloids. U. S. Dept. Agr. Bul. 1311.

(15) Rösler, H. 1902 *Neues. Jahrb., Beil.* 15: 231. (Cited by F. W. Clarke in Data of Geochemistry, Washington, 1908, p. 416.)

(16) Schwarz, R., and Walcker, R. 1925 *Ztschr. Anorgan. Chem.* (B) 145: 304–310.

(17) Splichal, J. 1921 The colloidal system silica-alumina. *Chem. List.* 15: 53–56; 88–90; 110–113; 140–143; 164–167.

(18) Wiegner, G. 1924 Boden und Bodenbildung in Kolloidchemischer Betrachtung, ed. 3. Dresden und Leipzig.

(19) Wiegner, G. 1925 Dispersität und Basenaustausch (Ionenaustausch). *Kolloid Ztschr.* (Ergänzbd., Zsigmondy Festschrift) (B) 36: 341–369.

(20) Wüst, E. 1907 *Ztschr. Prakt. Geol.* 1907: 19. (Cited by F. W. Clarke in Data of Geochemistry, Washington, 1908, footnote p. 416.)

CALCIUM AS A FACTOR IN SOYBEAN INOCULATION[1]

ROBERT W. SCANLAN[2]

University of Missouri

Received for publication August 13, 1927

From a consideration of the literature on the subject of symbiotic nitrogen fixation, it is apparent that differences of opinion are common concerning both the manner in which fixation occurs, and the various factors influencing fixation. This study was begun on account of the difficulty experienced in securing nodulation of soybeans on certain soil types in Missouri and Illinois.

HISTORICAL

Only those articles will be included in the historical résumé which deal directly with the phases under consideration in this report.

Perkins (14) reports that the elements essential for plant growth do not directly affect the nodulation of legumes.

Alicante (1) has made some observations on certain factors outside of the plant which are important in nodulation. The number of plants which he uses and the frequencies of his observations are so few that normal variation in nodule production is likely to be greater than the effect of his treatments.

The effect of phosphorus on nodulation has been noted by many workers. Flamand (5) and Marchal (12), working with water cultures; Eichinger (4), Laurent (9), Truesdell (18), Wohltmann and Bergene (20), Lohnis (11), Deherain and Demoussy (2), Prucha (15), Hutcheson and Wolfe (7), Wilson (19), working with soil; and Thornton and Gangulee (17), dealing with alfalfa inoculation, all report an increased number of nodules where phosphates were used.

The effect of calcium hydroxide on nodulation was first observed by Salfeld-Lingen (16) in 1900, who secured nodulation of peas only when limestone was used. Marchal (12), working with water cultures, found that the salts of calcium and magnesium favored nodulation, and Laurent (9) and Donnan (3) likewise, observed that lime stimulated nodule formation. Moore (13) also noted the variable effect of calcium and magnesium under both alkaline and acid conditions. Prucha (15) noted that calcium chloride, when added to the soil, inhibited nodulation of the Canada field pea. Wilson (9), however, observed that calcium compounds were in most cases effective in stimulating nodulation, with the carbonate radical showing no effect whatever. Lipman and Blair (10), working with soybeans, and Karraker (8) and Hudelson (6), working with red clover, observed that nodules were more numerous and better distributed on soil where limestone had been used.

[1] Portion of a thesis submitted to the faculty of the University of Missouri in partial fulfillment of requirements for the degree of Master of Arts.

[2] Graduate assistant in Soils, College of Agriculture, University of Missouri, 1924–26.

Especial credit is given to Dr. Wm. A. Albrecht, under whom the author worked, for his valuable suggestions and criticisms, and for his invaluable aid both in conducting the problem and in the preparation of this paper.

Marchal (12) noted that potassium salts prevented nodule formation. Prucha (15) observed that potassium nitrate inhibited nodule formation, whereas potassium acid phosphate and potassium hydroxide increased nodulation. Hutcheson and Wolfe (7) found that potassium chloride and potassium sulfate had no effect whatever on soybean nodulation.

OBJECT OF EXPERIMENT

This study was concerned with only certain specific factors of nutrition and environment of the legume plant and the infecting organism, and gives consideration to the following points:

1. The possible effect of standard soil amendments on the nodulation of soybeans grown on variously treated pots of certain soils in Missouri and Illinois.

2. The effects on soybean nodulation of calcium, phosphorus, and potassium treatments individually on the above soils.

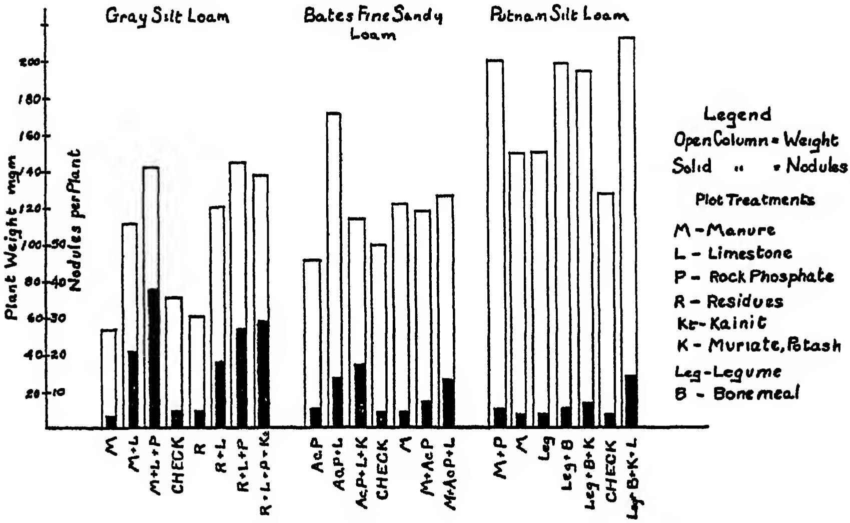


FIG. 1. NODULATION AND GROWTH OF SOYBEANS AS INFLUENCED BY SOIL TREATMENTS ON THREE DIFFERENT SOIL TYPES

3. The effect of calcium on the viability of *Bacillus radicicola* of soybeans, and on the nodulation of soybeans grown in solution.

4. The possibility of salt treatment of soybean seeds at the time of inoculation in order to increase nodulation.

EXPERIMENT 1

Samples of soil were collected from plots of Missouri and Illinois outlying experiment fields under treatments customary with these stations as listed in figure 1. These fields are located on soil areas giving difficulty in securing satisfactory nodulation of soybeans. These were the Gray Silt Loam on tight clay from southern Illinois, the Bates Fine Sandy Loam from southwestern Missouri, and the Putnam Silt Loam from northeastern Missouri.

The soils are all old farming land, mature in development, and of an acid reaction ranging from pH 5.0 to 6.8.

The Gray Silt Loam soil was secured from the Illinois Soil Experimental Field at Newton, Illinois; the Bates Fine Sandy Loam was taken from the Missouri Soil Experimental Field at Eldorado Springs, Missouri; and the Putnam Silt Loam soil was procured from the Missouri Soil Experimental Field at Vandalia, Missouri.

Methods. Weighed amounts of soil from each plot, representing different field treatments, of the three experiment fields were put into gallon pots in triplicate, with the exception of plot 4 of the Bates Fine Sandy Loam, which was made up in duplicate. Each pot was treated with a pure culture solution of the soybean organism at planting time and on three alternate days following. Five Virginia soybean plants were grown per pot and harvested at maturity. The weights of the harvested tops were determined on an oven-dry basis. The soil mass was worked over a fine screen and all the roots and nodules were carefully separated and saved. A careful count of nodules was made and their distribution noted. The oven-dry weights of the roots and nodules were taken and the entire plants saved for later analysis.

Results. The data gathered on the effect of soil treatments on the growth and nodulation of soybeans are given in figure 1 for the three soil types. They indicated in general:

(a) That limestone is important in nodulation, either from the standpoint of calcium content or soil reaction, or possibly both, also

(b) That potassium and possibly phosphorus are to be considered as factors influencing nodulation of soybeans on these soil types.

Individual effects of calcium, phosphorus, and potassium

The next step consisted in a repetition of the previous series with modifications in some of the soil treatments to determine the individual effects of calcium, phosphorus, and potassium. The same methods of planting, inoculating, and harvesting were used as before. The Morse variety of soybeans was substituted for the Virginia. Both the phosphorus and the potassium fertilizers were added in amounts equivalent to common field rates of application. Calcium acetate was selected to supply calcium because it would not greatly alter the pH of the soil.[3] One of the triplicate pots in the modified treatments was left untreated as a check. All other pots of the soils from the three different fields were repeated without further soil amendments. The new treatments and the plots concerned are given in table 1.

The plants in all pots were reduced to the best five, 8 days after seeding.

[3] It was found that the quantity of calcium acetate applied on the pots was too concentrated for the seedlings. The soils of these pots were removed, mixed with twice their weight of tap water, allowed to stand 3 hours, decanted, then the process repeated. The soil was then dried, returned to the pots, and the plants again set out and bacteria applied.

Even at this early date the small plants, growing in the presence of calcium acetate had formed several nodules. Plate 1, figure 1, showing the Gray Silt Loam pots, illustrates, in general, the variations in more mature growths, due to the new fertilizer treatments. The calcium acetate treatments were outstanding, as the plants were larger than their checks, with large, smooth, fleshy leaves of a dark green color. The data showing the effect of field fertilizer treatments and additional greenhouse salt treatments upon nodulation are given graphically in figure 2 for the three soil types used. Plate 1, figure 2, illustrates the increased nodulation and greater size of root system wherever limestone occurs in the soil treatment.

In general it is apparent that in the absence of limestone on these three acid soils, nodulation is extremely poor. Many workers have observed this fact

TABLE 1

Modified treatments of Gray silt loam, Bates fine sandy loam and Putnam silt loam

MODIFIED TREATMENTS	POT NUMBERS AND PREVIOUS FIELD TREATMENTS					
	Newton	Previous treatment	Eldorado Springs	Previous treatment	Vandalia	Previous treatment
Sodium acid phosphate*	2 J	Manure	4 G	Acid phosphate	3 m	Legume
	2 K	Manure	4 H	Acid phosphate	3 n	Legume
	2 L	Manure			3 o	Legume
Potassium chloride†	5 J	Check	1 G	Check	2 m	Manure
	5 K	Check	1 H	Check	2 n	Manure
	5 L	Check	1 I	Check	2 o	Manure
Calcium acetate‡	6 J	Residues	5 G	Manure	6 m	Check
	6 K	Residues	5 H	Manure	6 n	Check
	6 L	Residues	5 I	Manure	6 o	Check

* At the rate of 300 pounds acid phosphate equivalent per two million.
† At the rate of 100 pounds per two million.
‡ At the rate of 3 tons limestone equivalent per two million.

with other soils and have in most instances attributed the effect to the acidity of the soil. However, in the present work with three different soil types, the effect of limestone can be duplicated and even bettered by applying calcium acetate on the untreated soils. It is concluded, therefore, that where limestone increased nodulation in these soils it did so not only by altering the pH of the soil, but by supplying calcium to the infecting organism, which probably requires that element for its physiological activity. With regard to the nodulation of soybeans, on the three soils used, limestone seems far more important as a source of supply of calcium than as an adjustor of the soil reaction.

Results and discussion

The completion of this part of the work showed that limestone on all three soils increased nodulation. Rock phosphate or potash gave no significant increase in nodulation on the Gray Silt Loam, whereas calcium acetate gave a very remarkable increase. These pots, as was true of the corresponding treatments of the other two soils, had practically the same pH at the close as at the start of the experiment. Yet on the Gray Silt Loam calcium acetate gave a 1089 per cent increase in nodulation and on the Putnam Silt Loam a 433 per cent increase, whereas on the Bates Fine Sandy Loam the calcium-treated pots had more than twice as many nodules as the old limed pots, and more than ten times as many as the checks.

Phosphates increased nodulation on the Bates Fine Sandy Loam whereas potassium was ineffective.

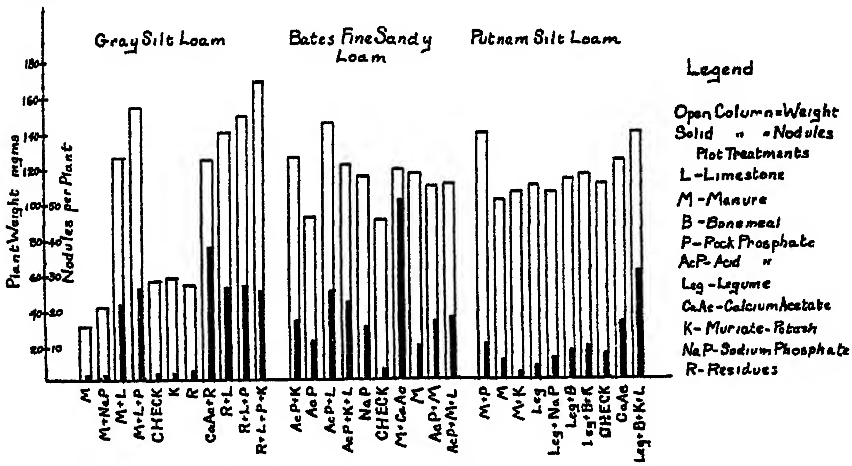


FIG. 2. NODULATION AND GROWTH OF SOYBEANS AS INFLUENCED BY PHOSPHATE, POTASH, AND CALCIUM ACETATE

Neither rock phosphate, bone meal, nor sodium di-hydrogen phosphate gave increases in nodulation on the Putnam soil. Potassium was likewise ineffective.

EXPERIMENT 2

Calcium in solution

Since preliminary results indicated that increased nodule numbers were correlated with calcium treatment of the soil, it was decided to study this point more expressly.

In order to study and possibly isolate calcium as a factor determining nodulation on soybeans, water cultures were used. *Bacillus radicicola* of soybeans was kept in tap water, and in tap water containing calcium chloride.

The same organism was also put into soil extract of acid Putnam Silt Loam, made in the ratio of 1 part soil to 5 parts of distilled water, and an inoculation was also made into a similar extract to which calcium chloride had been added.

The soybean nodule organism, stored for 60 days in the water cultures and for 90 days in the soil extracts, served as sources of inoculant for soybean plants in an experiment so arranged that soybean plants grown in the Putnam Silt Loam extract, both with and without calcium, were inoculated with each of the above sources of bacteria after their respective storage intervals. These were grown until the plants had developed several sets of leaves, at which time counts were made of the nodules on the plant roots. The data are reported in table 2.

TABLE 2

Viability of and infection by Bacillus radicicola as influenced by presence and absence of calcium salt in liquid media

BACTERIAL STORAGE MEDIUM	PLANT GROWTH MEDIUM	NUMBER OF PLANTS	AVERAGE NODULES PER PLANT
First trial (after 60 days storage of bacteria)			
Water and calcium salt†	Soil extract*	10	37.5
Water and calcium salt†	Soil extract*	10	12.1
Water only	Soil extract*	10	.6
Water only	Soil extract*	10	2.8
Second trial (after 90 days storage of bacteria)			
Soil extract and calcium salt†	Soil extract and calcium*	5	17 0
Soil extract and calcium salt†	Soil extract	10	18.2
Soil extract only	Soil extract and calcium	15	10.3
Soil extract only	Soil extract	15	2.2

* All solutions were used at a pH of 5.7.

† Calcium chloride, 1 part to 1500 of water.

An effort was made to determine the concentration of calcium chloride in solution most effective in increasing nodulation. Various concentrations were made up in distilled water. Soybeans were grown in each and repeatedly treated at the outset with a pure culture of the soybean organism. Upon maturity, the nodulation was studied and found to increase with the increase in calcium salt concentration as far as the ratio of 1 part calcium to 1500 parts water. Beyond this concentration, nodulation decreased.

The latter experiment was repeated under more carefully controlled conditions. The pH of each solution used was determined electrometrically and the plants were again thoroughly inoculated with a pure culture of the soybean organism.

The correlation of nodule production with concentration of calcium chloride is graphically represented by figure 3.

Salt treatments on seed

Since previous results indicated that certain salt treatments on soils were important factors in the nodulation of soybeans, a field test of the influence of these treatments when applied with the seed was attempted. Two locations on the Putnam Silt Loam were selected near Columbia, Missouri; one called Project 1, on unlimed soil, and the other Project 2, on limed soil. The later soil had received 2 tons of limestone per acre just previous to the time of planting the soybeans. Both soils were originally acid in reaction. Treatments of fertilizers were applied in the row at the time of seeding. In cases of those

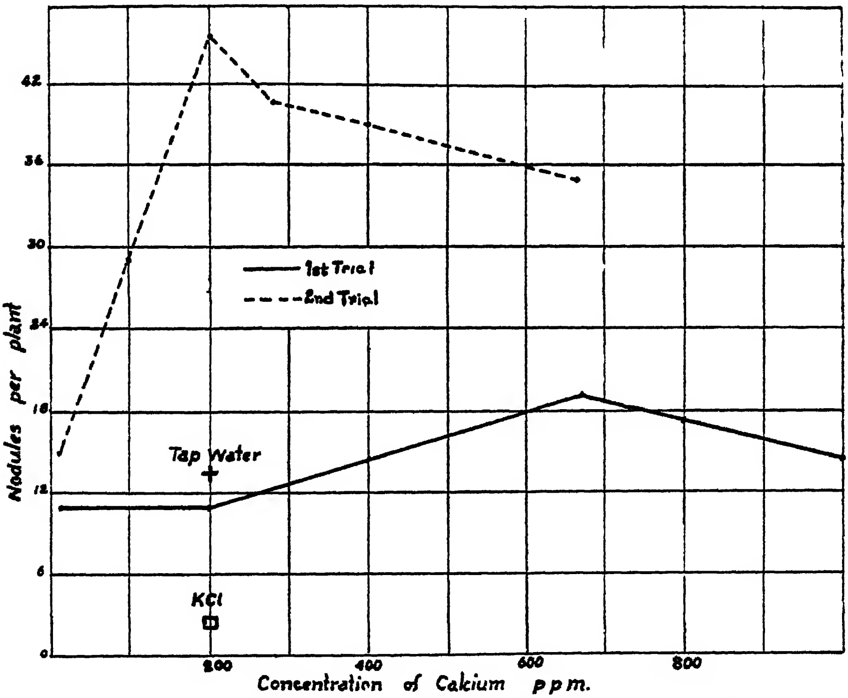


FIG. 3. NODULATION OF SOYBEANS AS AFFECTED BY CALCIUM CHLORIDE

seed treatments which applied chemicals to the seed coat, the seeds were first inoculated, then sprinkled with dry soil, and then with the fertilizing materials. In cases where the salt used was readily soluble in water, a 0.04 normal solution was sprinkled on the seed after treatment with a pure culture of bacteria, and then enough fine dry soil mixed with the beans to absorb the moisture. The limestone used was 100-mesh or finer. During various stages of maturity, plants were dug and nodules counted. The results are given in table 3. A photographic record made of some soybean roots from various treatments on project 1 is shown in plate 1, figure 3.

Susceptibility to inoculation

Naturally, in this connection, the question arises as to the possible methods through which calcium is instrumental in giving better inoculation. Increased numbers of nodules are possible either by a large infection during the plant's early growth, or by added infection during growth. Calcium salts may either help the initial infection, or may bring about added infection during growth. The latter seems to be the most plausible means by which intensive and distributed nodulation is possible on a root system of continuous growth. If this is true, calcium must be instrumental in extending the period over which the bacteria are viable and actively infective, and the plant must remain susceptible to inoculation during this time. Bacterial cultures treated with calcium and stored suggested that calcium lengthens their viability. Consequently, it was necessary to learn how susceptible the plant remains to inoculation during its life period.

TABLE 3

Nodulation of soybeans as influenced by various treatments applied with the seed

TREATMENT	NUMBER OF PLANTS EXAMINED	NODULES PER PLANTS	PLANTS NODULATED
Project 1. Unlimed soil			
			per cent
No treatment. Not inoculated	40	0.1	14
Limestone in row 52 pounds per acre. Inoculated	95	1.3	44
Limestone in row 183 pounds per acre. Inoculated	113	3.4	67
Limestone in row 183 pounds per acre. Inoculated; Phosphate* in row 78 pounds per acre. Inoculated	97	4.1	68
Lime hydrate in rows 52 pounds per acre. Inoculated	117	2.6	68
Lime hydrate in rows 183 pounds per acre. Inoculated	125	2.6	71
Lime hydrate in rows 183 pounds per acre. Inoculated; Phosphate in rows 78 pounds per acre. Inoculated	149	6.4	77
Calcium chloride solution on seed. Inoculated	165	5.7	86
Calcium nitrate solution on seed. Inoculated	110	11.8	97
Project 2. Limed soil			
No treatment. Not inoculated	72	0	0
Limestone on seed. Inoculated	89	0.3	34
Lime hydrate on seed. Inoculated	81	0.7	34
Phosphate on seed*. Inoculated	127	0.9	90
No treatment. Inoculated	76	4.3	83
Calcium chloride solution on seed. Inoculated	173	9.3	100

* Superphosphate (16 per cent phosphoric acid) was used.

Virginia soybeans were germinated for 5 days between blotters, and then set out in a duplicate series of 20 sand pots of 5 plants each. Beginning with

the day of planting and then on every other day thereafter, two pots of the series were thoroughly treated with a common source of *Bacillus radicicola*. This distributed the time of inoculation over a period of 18 days following setting out, or as late as 23 days following the planting of the seed. Three weeks after the bacteria were added, the examination for nodules of the series was begun by taking a pair of pots every other day. The roots were washed free of sand and the nodules counted. The results are recorded in table 4.

TABLE 4

Susceptibility of soybean plants to infection as influenced by the age of plant

TIME OF INOCULATION (DAYS AFTER PLANTING)	NUMBER OF PLANTS	TOTAL NUMBER OF NODULES
5*	10	237
7	10	125
9	10	79
11	10	5
13	10	5
15	10	30
17	10	0
19	10	0
21	10	10
23	10	0

* Beans were germinated 5 days between blotters. The first inoculation was given after this time, or when the germinating seeds were put into sand.

TABLE 5

Nodulation of soybeans at various stages of growth

AGE OF PLANTS	STAGE OF MATURITY	NUMBER OF PLANTS EXAMINED	NUMBER OF NODULES	AVERAGE NODULES PER PLANT
days				
33	Full growing period	50	80	1.6
47	Beginning to bloom	50	680	13.6
61	Full bloom—pods forming	50	885	17.7
75	Pods formed not filled	50	910	18.2
89	Pods filled—½ leaves dropped	50	935	18.7
103	Seed beginning to mature, two-thirds leaves dropped	50	365	7.3
117	Plants mature, all leaves dropped	50	270	5.4

During the summer of 1925, observations were made in the field on the effect of the age of the soybean plant on the number of nodules found on the roots. Virginia soybeans were planted close to a water supply so that the entire plant might be washed free of dirt at various intervals. All seed planted was inoculated with an extract of crushed soybean nodules. Beginning 33 days after planting, and every two weeks thereafter, 50 plants were harvested.

The roots were carefully washed free of dirt, and all nodules counted. The data are given in table 5.

It is apparent from the data in table 5 that a gradual increase in nodulation has occurred up to the first point of maturity[4] after which a very rapid decline in number of nodules occurred. Fully seven to eight weeks were required for the full development of nodules on the plants, indicating a long period over which the plant is susceptible to inoculation by the bacteria.

Results and Discussion

It is interesting to note that although the bacteria may stay viable in tap water for 60 days, their ability to infect the legume is lessened. The presence of calcium materially increases the chances for infection.

In general, as here determined, calcium as calcium chloride in concentrations between 1:1500 and 1:5000 parts is effective as a means of increasing nodulation of soybeans in water alone, whereas below these concentrations, the infecting power of the bacteria is disturbed.

The more soluble forms of calcium appear to be more effective, since the use of calcium, both in the form of calcium chloride and calcium nitrate, gave significant increases.

Infection generally occurs—according to the experiment on time of infection—at an early stage of plant growth; however, the number of nodules per plant increases up to the first stage of maturity, when a decrease in number occurs.

CONCLUSIONS

1. The results of this study indicate that the common soil amendments, such as crop residues, manure, and potash do not significantly influence the degree of nodulation of soybeans on the three acid soils used.

2. Acid phosphate, sodium acid phosphate, and bone meal on the Putnam Silt Loam, and rock phosphate and sodium acid phosphate on the Gray Silt Loam did not affect, in any great measure, the nodulation of soybeans. Both calcium acid phosphate and sodium acid phosphate, however, gave fair increases in nodule formation on the Bates Fine Sandy Loam soil.

3. Limestone was found to increase nodulation greatly in all instances where used.

4. That soil reaction was not the controlling factor on nodulation is shown by the fact that calcium acetate, when used on acid plots of each soil, although not greatly altering the soil reaction, increased nodulation 1089 per cent on the Gray Silt Loam; 1010 per cent on the Bates Fine Sandy Loam; and 433 per cent on the Putnam Silt Loam.

5. *Bacillus radicicola* kept in tap water for 60 days and in a Putnam Silt

[4] First point of maturity was taken to be the first stages of dying or when the plant deterioration began.

Loam soil extract for 90 days, suffered significant losses in its viability and ability to infect the plant, which were offset by the addition of 1 part of calcium, as calcium chloride, to 1500 parts of either of the above solutions.

6. The nodulation of soybeans grown in distilled water and in tap water containing calcium chloride increased with increased concentration of the salt up to that of 1 to 1500 in the former and of 1 to 5000 in the latter.

7. Calcium carbonate, hydrated lime, and acid phosphate used separately in the field, both on the soybean seed and in the row, did not increase nodulation on the Putnam Silt Loam. Calcium carbonate supplemented with acid phosphate, however, gave indications of some benefit to nodule formation.

8. Calcium nitrate and calcium chloride, when used on soybean seed on Putnam Silt Loam soil, not only increased nodulation but also increased the percentage of plants having nodules on their roots.

9. Infection of soybeans by *Bacillus radicicola* occured much more readily during the early stages of the plants' growth, but the plants were susceptible to infection until the first stages of maturity. This suggests that possibly the influence of calcium toward increasing inoculation is one of keeping the bacteria viable and infective during a long period of time.

REFERENCES

(1) Alicante, M. 1926 The viability of the nodule bacteria of legumes outside of the plant. *Soil Sci.* 21: 93–114.

(2) Deherain, P., and Demoussy, E. 1902 Culture de la luzerne zur des terres sans calcaire. *Compt. Rend. Acad. Sci. (Paris)* 134: 75–80.

(3) Donnan, A. V. 1912 Experiments on inoculation of lucerne. *Agr. Gaz. N. S. Wales* 23: 953–958.

(4) Eichinger, A. 1913 Regarding legume cultivation and inoculation experiments. Abs. in *Exp. Sta. Rec.* 27: 419.

(5) Flamand, H. 1904 Ueber den Einfluss der Ernährung auf die Entwicklung der Knöllchen der Leguminosen. *Ingén. Agr. Gembloux* 4: 755–765. Abs. in *Centl l. Agr. Chem.* 34: (1905) 738–740.

(6) Hudelson, R. 1915 The effect of limestone on certain soil constituents and on plant growth. M. A. Thesis, Univ. of Mo., p. 56.

(7) Hutcheson, T. B., and Wolfe, T. K. 1902 Fertilizer effect on soybeans. *Jour. Amer. Soc. Agron.* 14: 284–286.

(8) Karraker, P. E. 1914 The effect of liming on acid soil on growth of certain legumes. M. A. Theses, Univ. of Mo.

(9) Laurent, E. 1901 Observations sur le developpement des nodosites radicales chez les legumineuses. *Compt. Rend. Acad. Sci. (Paris)* 133: 1241–1243.

(10) Lipman, J. G., and Blair, A. W. 1920 The lime factor in permanent soil improvement. *Soil Sci.* 9: 91–114.

(11) Löhnis, F. 1902 Ein Beitrag zur Frage der Rotkleedüngung. *Mitt. Landw. Inst. Leipzig* 3: 1–49.

(12) Marchal, E. 1901 Influence des sels mineraux nutritifs sur la production des nodosites ches le pois. *Compt. Rend. Acad. Sci. (Paris)* 133: 1032–1033.

(13) Moore, Geo. T. 1905 Soil inoculation for legumes. *U. S. Dept. Agr. Bur. Plant Indus. Bul.* 71: 1–72.

(14) Perkins, A. T. 1924 The effect of several mineral fertilizers upon the nodulation of Virginia soybeans. *Soil Sci.* 17: 439–447.

(15) PRUCHA, M. J. 1915 Physiological studies of *B. radicicola* of Canada field peas. *N. Y. (Cornell) Agr. Exp. Sta. Mem.* 5: 9–83.

(16) SALFELD-LINGEN 1900 Welche Wirkung hat Aetzkalk in hohen, leichtem Sandboden auf die Leguminosenpilze. *Deut. Landw. Presse* 27: 931.

(17) THORNTON, H. G., AND GANGULEE, N. 1926 The life cycle of the nodule organism *Bacillus radicicola* (Beij.) in soil and its relation to the infection of the host plant. *Proc. Royal Soc. (London)*, Ser. B. 99: 427–451.

(18) TRUESDELL, H. W. 1917 The effect of phosphorus on alfalfa and alfalfa bacteria. *Soil Sci.* 3: 77–97.

(19) WILSON, J. K. 1917 Physiological studies of *Bacillus radicicola* of soybeans and of factors influencing nodule production. N. Y. (Cornell) Agr. Exp. Sta. Bul. 386.

(20) WOHLTMANN, F. W. 1902 Die Knöllehen Bakterien in ihrer abhangigkeit von Boden und Dungung. *Jour. Landw.* 50: 377–395.

PLATE 1

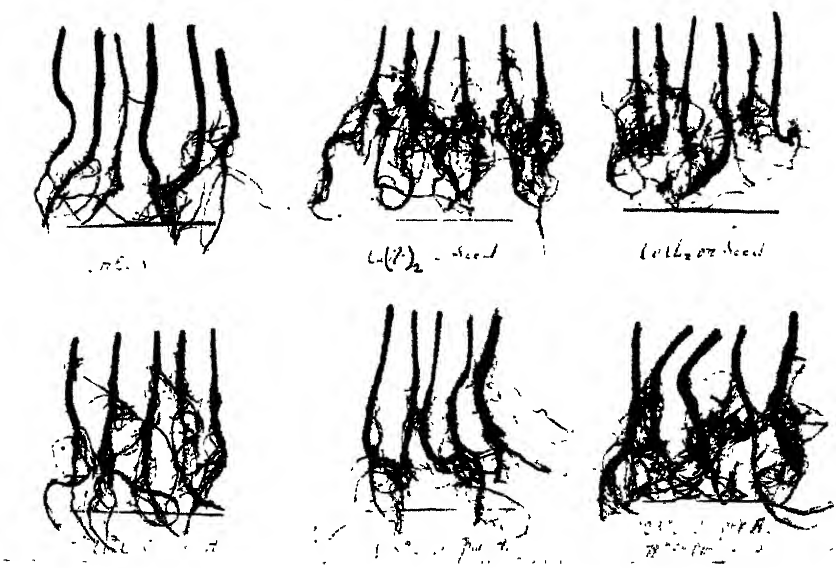
FIG. 1. The growth of soybeans as affected by phosphorus, potassium, and calcium treatments on gray silt loam. Left to right—Manure; manure and sodium acid phosphate; potassium chloride; check; residues and calcium acetate; residues and calcium acetate; residues.

FIG. 2. Root systems of soybeans showing variation in amount of nodulation as influenced by soil treatments. Left to right—Manure; manure and sodium acid phosphate; manure and limestone; manure, limestone, and rock phosphate; check; potassium chloride; residues; residues and limestone; residues, limestone, and rock phosphate; residues, limestone, rock phosphate, and kainit.

FIG. 3. The effect on nodulation of soybeans by various salt treatments on the seed (Project 1). Left to right—No treatment; calcium nitrate on seed; calcium chloride on seed; limestone (52 pounds) in row; limestone (183 pounds) in row; limestone (183 pounds) and acid phosphate (78 pounds) in row.

FIG. 1

FIG. 2



THE EFFECT OF DEHYDRATION OF SOILS UPON THEIR COLLOID CONSTITUENTS: III

J. L. STEENKAMP

School of Rural Economy, University of Oxford

Received for publication September 9, 1927

REVERSIBILITY OF CHANGES CAUSED BY DEHYDRATION

The experiments described in part I of this paper (6) and conducted for the purpose of estimating the effect of dehydration on the soil colloids, inevitably involve a factor which requires special attention if the effect of dehydration is to be clearly defined, namely, the reversibility of changes caused by dehydration. This condition of drying and again wetting the soil is absolutely compatible with field conditions, so much so that its inclusion in the paper was thought essential in order that more light might possibly be thrown on phenomena recorded experimentally and through experience, when a soil is dried out.

REVIEW OF LITERATURE

Cameron and Gallagher (2) show a variation in the volume of soils after repeated wetting and drying, depending on the previous condition of the soil. A condition of natural packing is ultimately reached, at which the expansion on wetting is equal to the contraction on drying.

Klein (4) found that the drying of a soil, previous to planting, has a beneficial effect on plant growth, and that the bacterial activity, as measured by carbon dioxide production, is increased by a previous drying of a soil: soil nitrification also increases, reaching a maximum with three dryings.

Van Bemmelen (9) showed that, unless dehydrated too far, the dried gel of silica eagerly reabsorbed water, though not so much as formerly, nor was the volume of the gel so great. He also worked with colloidal oxides of alumina, iron, and other metals. For ferric oxide and alumina, he found results similar to those for silica.

Ehrenberg (3) reports Schloesing as saying that an artificial clay may be obtained by mixing 1 per cent of glue with finely pulverized sand. This mixture exhibits reversibility of properties, such as cohesion and plasticity, on being dried and wetted alternately. He also quotes Mitscherlich to the effect that the moistening of dried humus soils is probably more closely connected with changes in the soil than with the restoration of colloidal properties. Also according to Zailer and Wilk, humus exhibits simple swelling phenomena but does not regain its original volume once in has been more or less dried.

Rohland (5) reports that the water absorptive power of soil colloids decreases after repeated drying, but that new colloids are formed by clay soil standing in an excess of water. It has also been shown by Ehrenberg and Pick (3) that dried soils absorb less moisture than already moist soils, but it is not known whether the difference is due to the effect of drying on the colloidal matter, or to the layer of absorbed air on the soil. Tempany (8) in studying the shrinkage of the soils of the West Indies, assumes that the gel condition of the colloidal material in those soils is restored by moistening and kneading the air-dry soil. In ceramics the practice of restoring the plasticity of clays, by keeping them soaked with water for several months, is a common one. This effect may be due to the production of the colloidal condition by hydrolysis.

Beaumont (1) found that, in the case of the air-dried soils, the hygroscopicity is clearly not immediately restored by re-moistening. He also found that after three months the difference in water vapor absorbed by moist and air-dried soils persists, and that this persistence is significant. Further data show that after three months the hygroscopicity of the remoistened soils did not return to an extent equal to that of the continually moist soils, indicating that with these soils the effect of drying on this property is not reversible within three months.

Alternate wetting and drying of soils did not affect the hygroscopicity after the first drying. With the subsoils that had been wetted and dried 32 times, there was a cumulative decrease in hygroscopicity, which was significant. It is possible that the surface soils do not show this cumulative effect, for, because of their natural subjection to alternate climatic wetting and drying, a sort of equilibrium has been established.

Hygroscopicity was decreased and the amount of change increased, successively by air-drying, oven-drying, and ignition.

Immersion of soil under 200 per cent of water for 2 years increased the hygroscopicity of a soil poor in organic matter, and decreased it in one rich in organic matter. The long soaking possibly increased the absorptive capacity of the soil poor in organic matter, by the hydrolysis of the inorganic constituents, thereby producing the colloidal condition. The decrease in soil, rich in humus, can be accounted for by the decomposition of the colloidal organic matter. immersion of a soil for 2 years also increased its absorptive capacity for methylene blue.

Beaumont also showed that drying a soil decreased the amount that could be suspended in distilled water and in 4 per cent ammonia. His results also show that air-drying increased the solubility of the colloidal matter of the humus, if not the humus itself.

Experimental work

It would appear from the literature cited here that the permanency of the effect of drying on hygroscopicity is fairly well established, so that it is unlikely that experiments conducted under parts I and II of this paper (6) would be affected by the reversibility of the colloidal condition. Although doubtless negligible for experimental purposes, it is worth noting that the same period of immersion will have different effects on different types of soil.

Experiments were conducted to establish the comparative recovery of different air-dried soils and the dry yellow clay-soil with regard to the absorption of deci-normal ammonium chloride solution for different periods. The dry soil was dehydrated in different artificial atmospheres over concentrated sulfuric acid.

Comparative recovery of air-dried soils as determined by absorption of deci-normal ammonium chloride solution. Adequate quantities of air-dried soils were shaken with 200 cc. deci-normal ammonium chloride solution in a mechanical shaker for 3 hours and left to stand, with occasional handshaking, for a period of 21 days. The difference in amount of ammonium chloride in solution before and after treatment gave the amount of salt absorbed by the soil.

As shown elsewhere (7, table 1), the air-dried sandy humus is the only soil which was compared to the light black clay and the yellow clay, that shows an increase of absorption of ammonium chloride solution after a period of 21 days. In fact, the light black and the yellow clays show a decrease of 2.37 and 5.61 mgm. equivalents respectively as compared to the increase of 0.95 mgm. equivalents for the sandy humus soil. Possibly the presence of organic

TABLE 1

Comparative recovery of air-dried soils and yellow clay soil (No. V) dried in artificial atmospheres as determined by absorption of deci-normal ammonium chloride solution

TYPE OF SOIL	CONDITION AND TREATMENT	ON 100 GM. DRY SOIL		
		N absorbed	$(NH_4)_2O$ absorbed	Absorption of 0.1 *N* NH_4Cl
		mgm.	*mgm.*	*mgm. equiv.*
Sandy Humus (I)	Moist (24.59 per cent H_2O)—2 days	176.9	321.4	12.34
	Air-dried (6.0 per cent)—2 days	147.5	274.3	10.53
	Air-dried (6.0 per cent)—21 days	160.8	299.0	11.48
Light Bl clay-soil (II)	Moist (34.12 per cent)—2 days	413.3	768.5	29.50
	Air-dried (7.6 per cent)—2 days	215.6	401.0	15.40
	Air-dried (7.6 per cent)—21 days	182.4	339.2	13.03
Yellow Surface clay (IV)	Moist (37.94 per cent)—2 days	630.2	1117.1	45.01
	Air-dried (11.56 per cent)—2 days	315.4	586.2	22.51
	Air-dried (11.56 per cent)—21 days	226.9	421.8	16.90
METHOD OF DRYING YELLOW CLAY-SOIL	TREATMENT			
Complete dehydration over concentrated H_2SO_4 in atmosphere of CO_2	In solution for 2 days	222.4	413.4	15.88
	In solution for 21 days	257.6	478.8	18.39
Complete dehydration over concentrated H_2SO_4 in atmosphere of oxygen	In solution for 2 days	268.2	498.5	19.14
	In solution for 21 days	271.0	503.9	19.35
Complete dehydration over concentrated H_2SO_4 with air inside desiccator	In solution for 2 days	278.32	517.4	19.86
	In solution for 21 days	279.40	519.4	19.95
Moist soil	In solution for 2 days	630.2	1117.1	45.01

matter is somewhat responsible for this. It appears that through the decomposition of organic matter in soils I and II, very much more absorbing material is created, particularly by soil I, than in the case of the yellow clay-soil. All three soils might show on recovery a relative increase of absorptive power, and consequently a decrease in amount of bases exchangeable with solution of ammonium chloride under similar conditions. This is clearly seen with the yellow clay-soil. It is almost certain, however, that large amounts of organic matter in any soil will override this slight decrease in exchangeable bases, because of the creation of so much more unsaturated absorbing material than the clay fraction is, apparently, here capable of. Clearly as a result of the sandy humus ought to absorb more ammonium chloride than the clay soil under similar conditions.

Comparative recovery of yelllow clay-soil dried out in artificial atmospheres as determined by absorbtion of deci-normal ammonium chloride. A very striking difference can be noticed in comparing the figures obtained for recovery of absolutely dry yellow clay-soil (also 7, table 6) with those obtained for the same soil when air-dried and similarly left in ammonium chloride solution for 21 days. When this soil has been totally dehydrated it shows a definite recovery which is small, except in the case of dehydration in an atmosphere of carbon dioxide where it is fairly pronounced.

Total dehydration seems, therefore, to have facilitated the creation of more absorbing material when left to stand in ammonium chloride solution for same time, and this is especially the case, as in previous experiments, for carbon dioxide. There is hardly any difference in recovery of dry soil when dehydrated in atmospheres of oxygen and air.

Here again, as discussed in part II of this paper, the increased formation of unsaturated absorbing material would tend to increase the absorption of ammonium chloride, despite the decrease of exchangeable bases under the same conditions.

In dealing with these experiments it is advisable to consider the possibility of biological changes taking place when a soil is left to stand in ammonium chloride solution for 21 days. For comparative work, however, the error seems negligible.

CONCLUSION

1. When soil material is dried there is distinct cementation of fine material for all methods of analysis, and the flocculation of colloidal matter under conditions corresponding to those in the field is very significant. The biggest increase in this case is in the silt fraction.

2. Soils which are liable to decomposition (i.e. unweathered or partly so) on dehydration cause a decrease in the degree of saturation, whereas cultivated soils show an increase on being dried out. The increase is greatest for soils containing humus.

3. In these former types of soils the amount of exchangeable bases decreases according to dryness with a corresponding increase of acid-salt-forming bases,

the solubility of which, however, is depressed on prolonged dehydration, with a corresponding increase of neutral-salt-forming bases. The latter types of soils again show definite increases of exchangeable bases expecially prominent in a soil containing a good deal of humus.

4. Pasture soils show a slight recovery of base absorption toward the closing stages of dehydration. This is more pronounced in cases where the increase of acid-salt-forming bases is large. The base absorptive power of cultivated soils decreases fairly steadily, although the decrease for soil with a high humus-content is very much steeper toward the closing stages of drying-out.

5. The highest figure for acid-salt-forming bases going into solution with deci-normal acid, and the lowest figure for neutral-salt-forming bases (i.e. exchangeable bases) are given by soil dried out in an atmosphere of carbon dioxide, as compared to atmospheres of oxygen, nitrogen, and air. Of the various factors concerned, dehydration appeared to be the most effective.

6. The absorption of salts, except phosphate, decreases according to dryness, that of phosphate depending on whether there is an increase or decrease of exchangeable bases in the soil. The availability of bases (correlation of bases held by the soil and absorption of deci-normal ammonium chloride) is highest for light clay-soil containing a good deal of humus.

7. The optimum moisture content, i.e. the point below which the bases in the soil are available, is lowest for black clay-soil and highest for sandy humus, the two pasture soils ranging in between. The amount of available bases is highest for black clay-soil.

8. Only air-dried soil of high humus content showed reversibility of the colloidal condition after 21 days. Yellow pasture soil containing very little humus dried out in different artificial atmospheres over concentrated sulfuric acid, showed a very slight recovery after 21 days in all cases, except in the case of a carbon dioxide atmosphere, where a very significant recovery is recorded.

BEARING OF THESE RESULTS ON CULTURAL CONDITIONS

The drying of a soil is a most powerful natural factor in helping in the transformation of plant nutritive substances from a potential to an active form; and the resulting increased fertility of the soil can hardly be dissociated from the improved physical condition due to flocculation of the soil colloids.

It appears that normal cultivated soils are more sensitive to a short period of drying, in that the mineral fertility elements are liberated far more freely and to a greater extent than in less weathered soils, under similar conditions of dehydration. Only under a prolonged period of dryness will an unweathered soil be able to liberate plant sustaining substances in the same proportion as the cultivated soil, because the absorption capacity will decrease only after a sufficient depression of absorbing material has occurred. Hence after severe conditions of dryness, and a consequent heavy rainfall, the unweathered soil will be exhausted of its plant-food, whereas the cultivated soil would still contain a storehouse of nutritive substances, which can respond to the needs of the plant when necessary.

This exhaustion effect of teaching in the weathered type will, however, be considerably counteracted if the soil contains a fair amount of humus, because of the more complete reversibility of the dehydration and the consequent absorptive power of the latter. If such a soil, therefore, contains enough organic matter, the storehouse of plant-food will ultimately be re-established.

The addition of organic matter, if necessity demands, would be less efficacious for well weathered than less weathered soils on drying out. In the former case, the organic matter would act only ultimately as absorbing material to liberated mineral constituents from soil and to plant-food derived from its own decomposition. In the latter, however, the soil will immediately retain the nutritive substances derived from the decomposition of the organic matter, because of fresh absorbent.

Various workers have definitely established the increase of the two fundamental nutrient substances, nitrogen and phosphorus, when a soil is dried out. Now if the two types of soil under discussion are again considered, it will be found that in both cases decomposition due to drying will increase the ammonia and amide nitrogen, and possibly phosphorus, but that only the unweathered soil, because of its greater absorbing capacity, will absorb these nutrient substances for the future use of the plant. In the case of the cultivated soil, a fairly high percentage of this new plant-food will be lost for the future use of the plant. Any semi-weathered soil would, therefore, be most efficient for the purpose of increased soil fertility, when conditioned by drying out, because it would then possess immediately available plant-food, together with a store at the disposal of the needs of the plant. On the same lines, one can safely say that the older a soil becomes, the less will it respond to drying for the purpose of soil fertility; therefore, a rest with as much moisture as possible seems essential for its recovery.

REFERENCES

(1) Beaumont, A. B. 1919 Studies in the reversibility of the colloidal conditions of soils. *(Cornell) Agr. Exp. Sta. Mem.* 21.

(2) Cameron, F. K., and Gallagher, F. E. 1908 Moisture content and physical condition of soils. *U. S. Dept. Agr. Bur. Soils. Bul.* 50: 1–70.

(3) Ehrenberg, P. 1915 Die Bodenkolloide. Dresden and Leipzig.

(4) Klein, W. A. 1915 Studies in the drying of soils. *Jour. Amer. Soc. Agron.* 12: 49–77.

(5) Rohland, P. 1914 Die Kolloide der Tonigen und Humusboden. *Naturw. Ztschr. Forst. u. Landw.* 12: 380–385.

(6) Steenkamp, J. L. 1928 Effect of dehydration of soils upon their colloid constituents: I. *Soil Sci.* 25: 163–182.

(7) Steenkamp, J. L. 1928 Effect of dehydration of soils upon their colloid constituents: II. *Soil Sci.* 25: 239–251.

(8) Tempany H. A. 1917 The shrinkage of soils. *Jour. Agr. Sci.* 8: 312–330.

(9) Van Bemmelen 1909 Beitrag zur Kenntnis der Eigenschaften der Hydrogels bei ihrer Entwässerung und Wiederwässerung. *Ztschr. Anorgan. Chem.* 62: 1–23.

THE EFFECT OF POTASSIUM SALTS ON THE AVAILABILITY OF NITROGEN IN AMMONIUM SULFATE[1]

W. B. MACK AND D. E. HALEY

Pennsylvania Agricultural Experiment Station

Received for publication November 4, 1927

The data given in table 1 are from certain plots of a fertilizer experiment with vegetables in rotation. This experiment had been in progress for ten years when these summaries were compiled. The rotation consists of early cabbage, early potatoes, tomatoes, and wheat followed by grass and clover in the order named. Complete summaries for the first ten years of the experiment are published in bulletin 210 of the Pennsylvania Agricultural Experiment Station.

TABLE 1

The effect of muriate of potash on yields from ammonium sulfate

CROP	MEAN YIELDS IN TONS PER ACRE						ODDS* BY "STUDENTS" METHOD THAT DIFFERENCES ARE NOT DUE TO CHANCE	
	A	B	C	D	B − A	D − C		
	Ammonium sulfate and acid phosphate	Sodium nitrate and acid phoshate	Ammonium sulfate, acid phosphate, and muriate of potash	Sodium nitrate, acid phosphate, and muriate of potash	Gain for sodium nitrate with acid phosphate only	Gain for sodium nitrate with acid phosphate and muriate of potash	B − A	D − C
Early cabbage	8.73	10.60	7.59	11.42	1.87	3.73	54.5:1	535.0:1
Early potatoes	2.61	2.98	2.54	4.07	0.37	1.53	17.1:1	216.0:1
Tomatoes	10.22	11.13	9.44	14.72	0.91	5.28	4.37:1	132.0:1

* Odds less than 30:1 show that the significance of the difference is questionable.

The respective carriers supplied the following plant-food materials per acre: N, 60 pounds; P_2O_5, 100 pounds; K_2O, 80 pounds.

From these data it appears that the addition of muriate of potash decreased the availability of the nitrogen in ammonium sulfate in these soils. In order to ascertain whether this was true, the following experiment was undertaken. This investigation involves a study of the effects of potassium- and chlorine-bearing compounds, alone and in combination, on the nitrification of ammonium sulfate.

[1] Approved by the Director of the Experiment Station as Scientific Paper No. 443.

PLAN OF THE EXPERIMENT

Soil was obtained from the strips separating the different tiers of the experimental vegetable plots. These strips were in sod and had received no fertilizer for ten years. One hundred-gram portions of this soil were taken after being screened and mixed with the different chemical compounds according to table 2. The samples were then placed in 150-cc. beakers and the original moisture content of 26.8 per cent was maintained by adding distilled water. Twenty-five series were set up, with 8 replicates in each series.

TABLE 2

Chemical treatments of the different series

BEAKER NUMBER	TREATMENTS—RATE PER ACRE									
	KCl	K_2CO_3	K_2SO_4	KNO_3	$CaCl_2$	$Ca(H_2PO_4)_2$	NaCl	$NaNO_3$	$(NH_4)_2SO_4$	NH_4Cl
	pounds	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*
1										
2	160									
3			137							
4		148								
5					236					
6								400		
7									311	
8	160							400		
9	160								311	
10			137					400		
11			137						311	
12						1000		400		
13						1000			311	
14	160					1000		400		
15	160					1000			311	
16			137			1000		400		
17			137			1000			311	
18		148				1000		400		
19		148				1000			311	
20		148						400		
21		148							311	
22				217			275			
23			137							252
24					236			400		
25					236				311	

All applications of K supply approximately the same amount of this element. The same holds true for nitrogen. With the exception of KCl, all chlorine treatments carry the same quantity of chlorine as used in the form of NH_4Cl.

The beakers were covered with opaque cardboard which was weighted with glass panes, and above these was placed moist sphagnum moss. The whole was

kept in a dark, well-aerated chamber. Moisture was added as lost from time to time. At the periods stated in table 3, two beakers were taken from each of the different series and the nitrate content determined by the phenoldisulfonic acid method. At the end of 7 weeks the soil in the beakers then remaining was taken out, mixed thoroughly and returned to the beakers, and brought to the proper moisture content. This was done in order to improve the aeration of the samples.

TABLE 3

Nitrate production as modified by chemical treatment

NUMBER OF BEAKER	TREATMENT	QUANTITY OF NO_3 PRODUCED			
		3 weeks	5 weeks	7 weeks	10 weeks
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	Nothing	6.4	10.0	40.0	38.9
2	KCl	9.1	14.7	25.1	37.0
3	K_2SO_4	13.3	18.6	25.4	40.2
4	K_2CO_3	6.3	14.1	22.5	41.7
5	$CaCl_2$	−3.3*	7.4	18.0	44.9
6	$NaNO_3$	15.4	15.4	7.1	45.3
8	$NaNO_3$ + KCl	15.4	11.1	14.3	43.2
10	$NaNO_3 + K_2SO_4$	−6.9	11.7	20.7	42.1
20	$NaNO_3 + K_2CO_3$	42.7	0.6	3.3	54.7
24	$NaNO_3 + CaCl_2$	−11.5	−4.8	8.3	50.0
12	$NaNO_3 + CaH_4(PO_4)_2$	10.5	11.7	27.4	42.9
14	$NaNO_3 + CaH_4(PO_4)_2$ + KCl	7.7	9.4	13.2	42.5
16	$NaNO_3 + CaH_4(PO_4)_2 + K_2SO_4$	15.0	1.0	14.5	34.4
18	$NaNO_3 + CaH_4(PO_4)_2 + K_2CO_3$	−6.4	0.0	28.9	52.4
7	$(NH_4)_2SO_4$	28.3	40.6	40.9	64.8
9	$(NH_4)_2SO_4$ + KCl	37.1	33.1	51.3	65.4
11	$(NH_4)_2SO_4 + K_2SO_4$	17.2	34.6	33.6	65.7
21	$(NH_4)_2SO_4 + K_2CO_3$	18.7	20.3	33.3	67.5
25	$(NH_4)_2SO_4 + CaCl_2$	21.4	15.0	34.4	69.3
13	$(NH_4)_2SO_4 + CaH_4(PO_4)_2$	38.6	35.3	40.3	70.9
15	$(NH_4)_2SO_4 + CaH_4(PO_4)_2$ + KCl	37.4	30.7	36.7	75.3
17	$(NH_4)_2SO_4 + CaH_4(PO_4)_2 + K_2SO_4$	35.7	29.4	31.6	68.1
19	$(NH_4)_2SO_4 + CaH_4(PO_4)_2 + K_2CO_3$	33.8	25.1	28.7	89.4
22	NaCl + KNO_3	−17.3	−3.7	12.8	40.3
23	$NH_4Cl + K_2SO_4$	6.8	16.1	34.5	60.7

* Minus signs indicate a decrease below the quantity of NO_3 present in the soil at the beginning of the experiment.

RESULTS OF THE EXPERIMENTS

The amounts of nitrates present at the end of stated intervals are given in table 3. The quantity of nitrates is expressed in parts per million of the extract obtained by shaking 100 gm. of the soil with 500 cc. of water, allowing to stand for 20 minutes, and filtering. The results are corrected for the amount of nitrate present in the soil at the beginning of the experiment, and for nitrates

added as part of the chemical treatments. The values given are averages of two beakers from each treatment, which in practically all cases were in very close agreement.

SUMMARY AND CONCLUSIONS

As shown in table 3, neither chlorine nor potassium compounds consistently inhibited the process of nitrification. In fact, in soils treated with ammonium sulfate, the rate of nitrification was greater at the end of the test for all additions of either chlorine or potassium compounds. The direct effect of potassium chloride on nitrification is evidently not the explanation of the situation presented in table 1.

Very rapid nitrification during the first three weeks was generally followed by a loss of nitrates during the following two weeks. Mixing the soil at the end of seven weeks resulted, on the whole, in increasing the rate of nitrification. This fact is noteworthy in view of its possible significance to future studies on the effects of fertilizers on nitrification.

Interchange of ions, $NaCl + KNO_3$ and $NH_4Cl + K_2SO_4$, instead of $NaNO_3 + KCl$ and $(NH_4)_2SO_4 + KCl$, respectively, decreased the rate of nitrification. The difference for the NO_3 interchange was practically the same as for the SO_4 interchange.

As shown in table 3, all fertilizers increased the rate of nitrification during the last three weeks, as compared to the unfertilized check. In the same period, potassium carbonate caused a higher rate of nitrification than either potassium chloride or sulfate. Potassium carbonate was associated with the largest quantity of nitrates present for any combination, both at the end of three weeks and at the close of the experiment.

Mono-calcium phosphate, during the last three weeks, tended to decrease the rate of nitrification for combinations containing sodium nitrate, but increased the rate of combinations with ammonium sulfate.

THE RELATION BETWEEN THE CONCENTRATION OF MINERAL ELEMENTS IN A CULTURE MEDIUM AND THE ABSORPTION AND UTILIZATION OF THOSE ELEMENTS BY PLANTS[1]

F. W. PARKER AND W. H. PIERRE

Alabama Polytechnic Institute

Received for publication January 5, 1928

It has long been assumed by many investigators that a thorough knowledge of the composition of the soil solution would make possible the solving of many problems regarding soil fertility and that differences in fertility would be more or less clearly reflected in the composition of the soil solution. The work on the displaced soil solution that has been conducted at the Wisconsin, California, and Alabama stations has solved several problems and at the same time has raised several other problems for investigation. One of the most important problems raised is that of the relation between the concentration of different mineral elements in a culture medium and the ability of agricultural plants to absorb and utilize those elements.

In a recent publication (2) one of the authors has shown that corn and soybeans will make maximum growth in culture solutions containing only 0.50 p.p.m. PO_4. Data were presented showing that with the procedure used the indicated phosphate concentration was not maintained. The results were taken to indicate that maximum growth of corn and soybeans might be secured in cultures containing only 0.15 or 0.20 p.p.m. inorganic PO_4. The bearing of these results on the phosphorus nutrition of plants growing in soil was discussed in some detail. It seemed apparent from the above data and those presented in another paper (3) that the concentration of inorganic phosphate in the displaced solution of many productive soils was not great enough to permit good growth of corn and soybeans.

In order to study the above problem in more detail, an additional experiment has been conducted on the growth of corn in culture solutions of varying concentrations of phosphate. This paper will present the results of that experiment and the results of an experiment on the growth of corn and soybeans in culture solutions of varying concentrations of potash.

CORN IN DIFFERENT PHOSPHATE CONCENTRATIONS

In this experiment the procedure used was essentially the same as that given in an earlier publication (2) except for the volume of the culture vessel. In the

[1] Published with the permission of the Director of the Alabama Agricultural Experiment Station. The writers express their appreciation to L. G. Brackeen for assisting in the conduct of these experiments.

present experiment 25-gallon galvanized cans were used as culture vessels and three corn plants were grown per culture. This affords approximately four and one-half times as much solution per plant as was used in the earlier work. In order to aerate and stir the culture solution, air was bubbled through the solution for a period of 2 mintues at intervals of 10 minutes. The culture solutions were analyzed twice a day, about 8:00 a.m. and 4:30 p.m., and KH_2PO_4 was added to renew the concentration of phosphate. The following concentrations of phosphate were used; 0.05, 0.10, 0.15, 0.20, 0.30, 0.40, and 0.50 p.p.m. The cultures were not in duplicate.

The corn was planted in quartz sand and after germination was transferred to the culture solutions. As in the experiments previously reported, iron was supplied for a period of 24 hours at intervals of about one week

TABLE 1

Average minimum concentration of phosphate in culture solutions whose indicated theoretical concentration was renewed twice a day

Volume of culture, 100 liters. Three corn plants per culture

PERIOD NUMBER	DURATION OF PERIOD	AVERAGE MINIMUM CONCENTRATION OF PHOSPHATE						
		0.05 p.p.m. PO_4	0.10 p.p.m. PO_4	0.15 p.p.m. PO_4	0.20 p.p.m. PO_4	0.30 p.p.m. PO_4	0.40 p.p.m. PO_4	0.50 p.p.m. PO_4
	days	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
1	6.0	0.035	0.071	0.121	0.17	0.26	0.34	0.44
2	5.0	0.038	0.064	0.114	0.13	0.24	0.29	0.40
3	5.0	0.035	0.048	0.087	0.12	0.19	0.24	0.32
4	5.5	0.037	0.042	0.057	0.12	0.15	0.18	0.42
5	5.0	0.028	0.025	0.028	0.12	0.10	0.22	0.41
Average..........		0.035	0.050	0.082	0.13	0.19	0.26	0.40

throughout the growing period. Since the cultures were analyzed twice a day, the variations in concentration and rate of phosphate absorption were studied. The results are given in tables 1 and 2.

Table 1 shows the average minimum concentration of phosphate in all cultures for five successive periods of growth. In the culture containing 0.05 p.p.m. PO_4 the minimum concentration was about the same at all times and was approximately 70 per cent of the theoretical or maximum. The minimum concentration in the culture containing 0.10 p.p.m. PO_4 varied from 0.071 p.p.m. in the first period to only 0.025 p.p.m. PO_4 in the fifth period. The average for the entire period was only 50 per cent of the maximum of 0.10 p.p.m. As the theoretical concentration was increased above 0.15 p.p.m. PO_4 the concentration was more nearly maintained. These results, particularly those for the concentrations of 0.10 and 0.15 p.p.m. PO_4, show in a very striking manner the rapidity of phosphate absorption from solutions of rather low concentrations. Three corn plants, 40 days after planting, reduced the

phosphate content of 100 liters of culture solution from 0.15 p.p.m. to 0.035 p.p.m. in 8 hours. This rapid absorption and consequent failure to maintain the phosphate concentration must be kept in mind when the growth secured at the various concentrations is considered.

In table 2 are recorded the milligrams of phosphate absorbed per day during five successive periods. These figures show very clearly the influence of

TABLE 2

Phosphate absorption by corn plants growing in culture solutions of various concentrations of phosphate

PERIOD NUMBER	DURATION OF PERIOD	PHOSPHATE ABSORBED PER DAY						
		0.05 p.p.m. PO_4	0.10 p.p.m. PO_4	0.15 p.p.m. PO_4	0.20 p.p.m. PO_4	0.30 p.p.m. PO_4	0.40 p.p.m. PO_4	0.50 p.p.m. PO_4
	days	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
1	6.0	3.1	5.8	5.8	6.8	8.3	11.8	12.5
2	5.0	2.4	7.2	7.2	14.0	12.6	21.2	20.8
3	5.0	3.0	10.6	12.6	17.0	21.6	32.8	35.4
4	5.5	2.7	11.6	18.7	16.5	29.3	43.5	15.8
5	5.0	4.4	15.0	24.4	15.4	39.2	36.0	18.0
Average..........		3.1	10.0	13.7	14.1	21.8	28.3	20.1

TABLE 3

Dry weight of corn grown in culture solutions of the phosphate content indicated

THEORETICAL	AVERAGE MINIMUM	DRY WEIGHT OF THREE PLANTS		
		Tops	Roots	Total
p.p.m.	*p.p.m.*	*gm.*	*gm.*	*gm.*
None	.....	1.2	1.0	2.2
0.05	0.035	11.1	6.9	18.0
0.10	0.050	31.1	18.6	49.7
0.15	0.082	39.1	22.8	61.9
0.20	0.130	43.0	21.0	64.0
0.30	0.190	53.1	22.0	75.1
0.40	0.260	55.7	26.8	82.5
0.50	0.400	42.3	25.0	67.3

phosphate concentration and stage of growth on absorption. Increasing the phosphate concentration increased absorption during the first three periods of growth. During the last two periods absorption in the culture containing 0.50 p.p.m. was slow and the plants had a rather stocky growth that was somewhat abnormal. In the cultures containing 0.10, 0.15, and 0.30 p.p.m. PO_4, absorption increased rather rapidly from the first to the last period. The culture containing 0.20 p.p.m. PO_4 seems to be rather abnormal in that phosphate absorption did not materially increase after the second period and

was much slower during the last period than the culture with 0.15 p.p.m. PO_4.

The dry weights of the plants are recorded in table 3. Maximum growth was secured at a concentration of 0.40 p.p.m. PO_4. The growth, however, at 0.15 p.p.m. PO_4 was very good and that at 0.10 p.p.m. was also good. As was indicated in table 2, the corn in these two cultures was absorbing phosphate very rapidly and making good growth at the time of harvesting. It is probable that if the phosphate concentration could have been maintained and if harvesting had been delayed the growth of the plants in cultures with 0.10 and 0.15 p.p.m. PO_4 would have approached the maximum more closely.

The results of this experiment indicate very clearly that if the phosphate concentration were maintained corn would make excellent if not maximum growth at a concentration of 0.10 p.p.m. PO_4. It does not appear, however, that good growth would be secured at a concentration of 0.05 p.p.m. PO_4. The bearing of these results on the phosphorus nutrition of plants in soil will be discussed later.

TABLE 4

Yields of corn and soybeans in culture solutions of different potassium concentration

SOLUTION NUMBER	CONCENTRATION OF K IN CULTURES	CORN			SOYBEANS		
		Tops	Roots	Total	Tops	Roots	Total
	p.p.m.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
1	0	0.65	....	0.65	....	...	....
2	0.5	3.60	1.10	4.70	....	...	....
3	2.0	11.88	3.15	15.03	12.3	3.1	15.4
4	5.0	14.30	3.70	18.00	12.2	2.6	14.8
5	10.0	15.50	4.00	19.50	....	...	....
6	25.0	12.70	4.10	16.80	13.4	3.5	16.9

CORN AND SOYBEANS IN DIFFERENT POTASSIUM CONCENTRATIONS

During the summer of 1926 an experiment was conducted to determine the minimum concentration of potassium necessary for maximum growth of corn and soybeans in culture solutions. The culture method was essentially the same as that previously described (2). With corn, one plant was grown in 7500 cc. of culture solution; with soybeans, two plants. All cultures were in duplicate. Tap water contained approximately 2.0 p.p.m. K so it was used in all cultures containing that or higher concentrations of potassium. Distilled water was used in the soybean cultures containing less than 2.0 p.p.m. K, while rain water was used in the corn cultures having less than 2.0 p.p.m. K. The potassium content of the cultures was maintained by renewing the solution once a day during the early part of the growing period and twice a day later when absorption was more rapid. Studies on absorption showed that this procedure was very effective in maintaining the concentration of potash. In

these cultures, therefore, the potassium content was more nearly maintained than was the phosphate content of the cultures of the preceding experiment. The corn was harvested 30 days and the soybeans 55 days after planting. The dry weights of the plants are given in table 4.

In this experiment maximum growth of soybeans was secured at a potassium concentration of 2.0 p.p.m. The plants in all cultures containing less than 2.0 p.p.m. K made very poor growth and died before the other plants were harvested. The cultures seemed to be toxic to the plants. This may have been due to some toxic substance in the distilled water used for these cultures, or it may have been due to a deficiency of some element in the culture. It probably was not due solely to a deficiency of potassium but that may have been a contributing factor. Although the experiment shows that maximum growth may be obtained at a concentration of 2.0 p.p.m. K, it does not show conclusively that good or maximum growth might not be secured at a lower concentration.

The maximum growth of corn was secured at a concentration of 10.0 p.p.m. K but excellent growth was secured at a concentration of 2.0 p.p.m. It is probable that a large part of the variation obtained in the dry weight of the last four cultures recorded in the table may be due to plant variation and experimental error. Apparently, therefore, corn will make maximum growth in culture solutions containing 2.0 p.p.m. K. Unfortunately, the plants in cultures containing 1.0 p.p.m. were lost because of insect injury and no data are available for that concentration. Rather poor growth was secured at a concentration of 0.50 p.p.m. K. This is proably due to a deficiency of potash, as this culture did not seem to have a toxic action on the corn plants similar to that noted with soybeans in cultures of the same concentration. The results indicate, therefore, that maximum growth of corn may be secured with 2.0 p.p.m. K.

These results with corn and soybeans are in rather good agreement with those obtained by Bartholomew and Janssen (1). They report that maximum growth of soybeans and tomatoes was secured at a concentration of from 3.0 to 5.0 p.p.m. K, and that whereas 2.0 p.p.m. was necessary for the maximum growth of oats, 1.0 p.p.m. was sufficient for alfalfa.

DISCUSSION

The experiments reported show that the corn plant will make excellent growth in culture solutions of very low concentrations of phosphate and potassium. When these results are considered in connection with studies on the composition of the displaced soil solution they should indicate whether the latter is adequate for plant growth. Unpublished data obtained in this laboratory show that the displaced solution of more than 20 soils contains from 4.0 to 710.0 p.p.m. K. The soil solution of most of the soils contained more than 10 p.p.m., and in only three soils was the concentration over 100

p.p.m. It is evident, therefore, that as regards potassium the concentrations found in the displaced solution of these soils are adequate for plant growth. It is entirely possible, however, that cropping would reduce the concentration in some of these soils so that there would not be enough potassium in the displaced solution to support good growth. The question of the ability of a soil to maintain a given concentration of potassium in the soil solution is very important but will not be discussed here.

The relation between the culture solution data and the composition of the displaced solution is not so clear in the case of phosphate as it is in the case of potassium. In the publication (2) previously referred to, this question was considered in some detail. The position taken at that time was that as regards PO_4 the soil solution was not adequate for plant growth and that root-soil contact was essential for the PO_4 nutrition of plants in many soils. Since then no additional data have been secured on the PO_4 content of the soil solutions, but, as just reported, an experiment indicates the possibility of securing maximum growth of corn at a phosphate concentration of 0.10 p.p.m.

The fact that the minimum concentration required for good growth has been found to be slightly lower than previously estimated does not alter the situation materially. There are several instances of soils whose displaced solutions contain from 0.05 p.p.m. to a trace of PO_4 and yet those soils produce good yields of corn. Apparently, therefore, root-soil contact is necessary for the absorption of sufficient PO_4 for good growth of corn and probably other plants. The nature of the absorption process and the reactions occurring in the root-soil system are as yet unknown. The possibility remains that there is a higher concentration of phosphorus in solution at the surface of the soil particle than in the solution obtained by the displacement method.

SUMMARY

An experiment is reported in which corn was grown in large volumes of culture solution, the phosphate content of which ranged from 0.05 p.p.m. to 0.50 p.p.m. PO_4. The results indicate that corn will make maximum growth at a concentration of 0.10 p.p.m. PO_4 if that concentration can be maintained throughout the growing period.

In a second experiment corn and soybeans were grown in culture solutions which varied in potassium concentration from 0.5 p.p.m. to 25 p.p.m. K. The results obtained show that both crops will make maximum growth at a concentration of 2.0 p.p.m. K or possibly less.

The bearing of these data on the question of the nutrition of plants growing in soils is discussed. The results are taken to indicate that in many soils the displaced soil solution is adequate for the potassium nutrition of plants but that in many soils, root-soil contact is necessary for the phosphate nutrition of plants.

REFERENCES

(1) Bartholomew, R. P., and Janssen, G. 1927 The rôle of potassium in plant nutrition. *Ark. Agr. Exp. Sta. Bul.* 221: 63.

(2) Parker, F. W. 1927 Soil phosphorus studies: III. Plant growth and the absorption of phosphorus from culture solutions of different phosphate concentrations. *Soil Sci.* 24: 129–146.

(3) Pierre, W. H., and Parker, F. W. 1927 Soil phosphorus studies: II. The concentration of organic and inorganic phosphorus in the soil solution and the availability of organic phosphorus to plants. *Soil Sci.* 24: 119–128.

THE ACTION OF NEUTRAL SALTS ON ACID SOILS WITH REFERENCE TO ALUMINUM AND IRON

SANTE MATTSON

Bureau of Soils, U. S. Department of Agriculture

Received for publication January 11, 1928

INTRODUCTION

When acid soils are treated with neutral salt solutions the acid filtrate will generally be found to contain aluminum and iron. There appears however to be an endpoint to the quantities thus removable, for upon continued leaching with the salt solution these cations decrease with the acidity and cease to appear as the filtrate approaches neutrality.

Regarding the nature of this reaction two opposing views are held. Kappen and his co-workers, who have most extensively occupied themselves with this problem, hold that a part of the aluminum and iron is present in the soil in an exchangeable condition and that the exchange acidity is due solely to the hydrolysis of their salts. Other investigators believe that the appearance of aluminum and iron is due to a secondary reaction between the liberated acid and the soil material. The cessation of the appearance of aluminum and iron when the filtrate approaches neutrality would be explained on the basis of the former view by the assumption that all of the exchangeable aluminum and iron has been displaced, and on the basis of the latter view by the fact that the decomposition of the soil material must cease with the removal of the liberated acid.

From the results of a recent discussion of this important problem it appears that no satisfactory evidence has been produced by the defenders of either of the above theories (6). The results of the following experiments should therefore serve to fill a gap in our knowledge of the action of neutral salts upon acid soils.

In his work on the electrodialysis of soil colloidal materials (3) the author found that after the soil material had yielded the major portion of the exchangeable mono- and divalent cations to the electric current, aluminum and later iron appeared in the electrodialysate. The quantities of aluminum and iron removable by the current were however, as in the case of the neutral salt treatment of acid soils, limited to a small portion of the total quantities present in the soil. Were it not for the following complications, this would apparently support the view of Kappen that a part of the aluminum and iron exists in the soil in the condition of exchangeable cations. In order to determine the exchange capacity of the electrodialyzed material this was then treated with a

hot, normal $CaCl_2$ solution (3, p. 563) with the result that renewed quantities of aluminum and iron appeared in the acid filtrate but only about two-thirds of the acidity could be accounted for by their presence. After the material was washed free from chlorides it was again electrodialyzed to determine the adsorbed Ca. This was found to be equivalent to the displaced hydrogen but the exchange capacity had suffered a reduction as compared with that of the original material. But most significant for the problem here dealt with is that aluminum and iron appeared again in the electrodialysate.

EFFECT OF DILUTE ACID AND NEUTRAL SALT SOLUTIONS

In order to determine to what extent aluminum and iron might be removed by a neutral salt solution from soil colloidal material which is rendered unsaturated (austauschsauer) by treatment with a dilute acid solution according to the method of Liesegang and Kappen (2) the following experiment was performed.

TABLE 1

Aluminum and iron extracted from 2 gm. of the Sharkey and the Norfolk soil colloidal materials by alternate treatment with acid and neutral salt solution

KIND OF TREATMENT	$Al_2O_3 + Fe_2O_3$ EXTRACTED FROM	
	The Sharkey	The Norfolk
	gm.	*gm.*
100 cc. 0.05 *N* HCl	0.0114	0.0017
100 cc. 0.05 *N* HCl	0.0049	0.0011
100 cc. 0.05 *N* HCl	0.0045	......
100 cc. 0.05 *N* HCl	0 0039	......
100 cc. 1.0 *N* NH_4Cl	0.0141	0.0053
100 cc. 0.05 *N* HCl	0.0004	Trace
100 cc. 1.0 *N* NH_4Cl	0.0061	......
100 cc. 0.05 *N* HCl	Trace	......
100 cc. 1.0 *N* NH_4Cl	0.0051	......
100 cc. 0.05 *N* HCl	Trace	......
100 cc. 1.0 *N* NH_4Cl	0 0061	......
100 cc. 0.05 *N* HCl	Trace	......
100 cc. 1.0 *N* $CaCl_2$	0 0045	......
100 cc. 1.0 *N* NH_4Cl + 0.05 *N* HCl	0.0075	0.0088

The colloidal material from the Sharkey clay soil and the Norfolk fine sandy loam subsoil were selected for this work. The former has an $SiO_2/Al_2O_3 + Fe_2O_3$ ratio of 3.18 whereas the ratio of the latter is only 1.63. The two materials have been discussed in detail in earlier publications (3, 4). Two grams of each material were treated on the filter, first with 100-cc. portions of 0.05 *N* HCl and then alternatingly with 100 cc. *N* chloride solution and 100 cc. 0.05 *N* HCl. Each treatment was followed by washing with water. The quantities of sesquioxides present in the several filtrates were then determined.

The Norfolk received only a few treatments but sufficient to show the general trend of the reaction. Both materials were given a final treatment with a N NH_4Cl solution which had been rendered 0.05 N with respect to HCl. The results are shown in table 1.

The experiment brings out the important fact that as often as the soil material is rendered unsaturated it will continue to yield aluminum and iron to the neutral salt treatment. Several other significant facts will be noted. The strong chloride solutions together with the liberated acid possess a much stronger solvent action than the dilute acid alone. That this is due to the high Cl-ion concentration, which in the presence of the free acid favors the formation of the soluble, normal chlorides of aluminum and iron, can easily be shown. Portions of precipitated $Fe(OH)_3$, dried at 110° and powdered were digested on the steambath in 0.05 N HCl and in mixtures of the same strength of acid and normal chlorides of Ca, K, and NH_4. The solvent action of the acid alone was very slight whereas the mixture of acid and either of the chlorides brought about a rapid solution. The same results were obtained with a dried artificial gel of silica, alumina, and iron oxide. Conversely, the hydrolysis of $FeCl_3$ will be found to be inhibited by a high Cl-ion concentration by adding a neutral chloride to one of two dilute solutions of $FeCl_3$. Upon warming, only that one of the solutions to which no chloride was added will turn dark brown, indicating extensive hydrolysis, a quantitative estimate of which may be obtained by adding a little K_2SO_4. The divalent SO_4 ion will rapidly flocculate the electropositive sol.

This influence of a high Cl-ion concentration explains why the dilute acid solution resulting from a displacement of the hydrogen ions in acid soils is able to dissolve equivalent quantities of aluminum and iron. This equivalence is held to be the strongest evidence in favor of the view that aluminum and iron are liberated by base exchange. Even Kelley and Brown, who otherwise are inclined to accept the view that these ions result from a secondary reaction, find it "hardly probable, that NH_4 replaced hydrogen thus producing a solution sufficiently acid to effect the solution of these bases" (1).

The above experiment further shows that the soil material contains a certain portion of aluminum and iron in a more reactive condition. The first treatments with dilute acid yielded considerable quantities of these elements but after the first treatment with the salt solution the acid was able to dissolve only mere traces. No significance should be attached to this difference in reactivity as it might be due to the often observed decrease in solubility of a mineral constituent which results when a less soluble constituent forms a protective coating. But if the view that the aluminum and iron liberated by the neutral salt treatment is wholly due to a secondary reaction with the liberated acid, is to be accepted, it might be more difficult to explain the fact that the initial, more easely reactive, quantities of aluminum and iron are much greater in the case of the soil material having the greatest exchange capacity, namely, the Sharkey, than in the case of the Norfolk although the latter

contains a much greater proportion of sesquioxides (4). This might however be explained on the basis of certain assumptions. It is conceivable that the surface silicate molecules, with which the exchangeable cations are associated, constitute in the unsaturated condition a particularly unstable part of the soil colloidal material. This would explain the reduction in the exchange capacity resulting from the neutral salt treatment of unsaturated soil materials. It is also possible that the aluminum and iron exist in a more reactive condition in soil colloidal materials of the nature of the Sharkey. This material is more dispersible and shows more pronounced colloidal behavior than the Norfolk. The latter belongs to the group of soil colloidal materials with a silica/sesquioxide ratio below 2 and which usually have a reddish or yellowish color. Such materials, from all indications, contain free sesquioxides (5). The aged gel of these oxides is not very dispersible and is chemically rather inert. Anyone who has worked with lateritic soils knows the truth of this statement. The greater quantities of aluminum and iron removed from the Norfolk by the last treatment, as shown in table 1, indicate that this material requires a more drastic treatment to dissolve these elements.

EFFECT OF NEUTRAL CHLORIDE AND DILUTE ACID

In order to determine the ultimate result of the continued action on the soil materials of a strong chloride solution in the presence of a small quantity of acid the following experiment was performed.

One gram each of the Sharkey and the Norfolk soil colloidal materials was placed in a flask containing 1 liter 4 N NH_4Cl to which 0.05 equivalent HCl was added. This quantity of acid was more than sufficient to combine with all the basic oxides present. To hasten the reaction the flasks were then placed on the steambath. After two months the residues were washed, ignited, weighed, and analyzed. The results are given in table 2.

The residues consisted in both cases of small quantities of silica and alumina with a trace of iron together with the entire quantity of titanium originally present in the materials. The latter was therefore the only component not affected by the treatment. All of the Ca and Mg, the exchangeable and the nonexchangeable alike, was dissolved. The disintegration was almost complete; the mere presence of a large quantity of the chloride carried the reaction much further than the acid alone would have done.

INDEPENDENCE OF THE EXCHANGE ACIDITY

Since all natural, acid mineral soils yield aluminum and iron when treated with a neutral salt solution it would be difficult to prove whether acidity may be developed in the absence of these elements, that is, whether the mineral soil material is, like peat, capable of bringing about a "Neutralsalzzersetzung." The author has found, however, that when soil colloidal materials are digested with a saturated solution of $AlCl_3$ a certain portion of the sesquioxides are removed by peptization without impairing the exchange capacity (5). On

treating the $AlCl_3$-digested materials, after a thorough washing with hot water, with a neutral salt solution unusually small quantities of aluminum appeared in the filtrate. In order to compare the acidity with the quantities of aluminum and iron liberated by the neutral salt treatment, 5 gm. of the Sharkey soil colloidal material, which had been digested with a saturated solution of $AlCl_3$ and thoroughly washed, were leached on the filter with 1 liter 4 N KCl solution. An examination of the filtrate showed 3.260 milliequivalents titratable acidity, 0.353 milliequivalents aluminum, and 0.040 milliequivalents iron. The acidity was therefore over eight times greater than what could be accounted for by the presence of the trivalent cations.

Although this experiment shows that exchange acidity in mineral soils is independent of the presence of aluminum and iron in the extract it is not denied that the cations of these elements enter into exchange reactions. Such reactions are not limited to any specific cation or groups of cations. In very acid soils the aluminum and iron cations may compete with the other cations in the exchange reactions but only in proportion to their concentration and to their specific energy of displacement. In soils of ordinary reactions the solubility product of the trivalent cations is so low that the cations may be looked upon as

TABLE 2

Analysis of residues

RESIDUE	WEIGHT OF RESIDUE	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TOTAL WEIGHT
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Sharkey.	0.0243	0 0171	0 0047	0 0027	Trace	None	None	0.0245
Norfolk.	0 0261	0 0110	0 0084	0 0065	Trace	None	None	0 0259

being completely removed from the sphere of action. The fact that the KCl solution extracted very little aluminum from the $AlCl_3$-treated material (the small quantities of aluminum and iron which were dissolved by the KCl solution must be ascribed to the progressive disintegration of the material) shows at least that it is not possible, adsorptively, to saturate a soil with aluminum as it is with a neutral salt cation. The inability of the soil material to adsorb aluminum ions from the $AlCl_3$ solution may be due to the acid reaction of the latter. It might also be due to the fact that the $AlCl_3$ rendered the material electropositive. In this condition soil materials apparently lose their power to adsorb and exchange cations. Soil colloidal materials having a very high sesquioxide content become electropositive in weak acids (even in CO_2 solution) and adsorb no cations from solutions of such acids (5). By precipitating $Al(OH)_3$ in the Sharkey soil colloidal material a loss in the power to adsorb cations from acid solution, in which the material was electropositive, was observed. In alkaline solutions, in which the material became again electronegative, no such loss was found. This problem, however, has not yet been subjected to a thorough investigation.

SUMMARY

1. Soil colloidal materials were given alternate treatments with 0.05 N HCl and 1.0 N neutral choloride solutions. Aluminum and iron were dissolved in appreciable quantities only by the first few treatments with the acid solution whereas with the chloride treatments considerable quantities of these elements were yielded continually each time the materials were rendered unsaturated by the preceding acid treatment. The reaction is due to the liberated acid, the activity of which was shown to be greatly increased by the high Cl-ion concentration of the salt.

2. A mixture of the acid and the salt solutions brought about a complete decomposition of the material.

3. That the exchange acidity is independent of the presence of aluminum and iron was shown in the case of specially treated soil colloidal materials.

REFERENCES

(1) Kelley, W. P., and Brown, S. M. 1924 Replaceable bases in soils. *Calif. Agr. Exp. Sta. Tech. Paper* 15: 29.

(2) Liesegang, H., and Kappen, H. 1922 Weitere Untersuchungen zur Austauschazidität der Mineralböden. *Landw. Vers. Sta.* 99: 191–230.

(3) Mattson, Sante 1926 Electrodialysis of the colloidal soil material and the exchangeable bases. *Jour. Agr. Res.* 33: 553–567.

(4) Mattson, Sante 1926 The relationship between the electrokinetic behavior and the base exchange capacity of soil colloids. *Jour. Amer. Soc. Agron.* 18: 458–470.

(5) Mattson, Sante 1927 Anionic and cationic adsorption by soil colloidal materials of varying $SiO_2/Al_2O_3 + Fe_2O_3$ ratios. Proc. First Internatl Cong. Soil Sci. Comm. II. Washington, D. C.

(6) Transactions of the Second Commission of the International Society of Soil Science, vol. B: 40–44. Groningen, Holland, 1927.

A BRIEF METHOD FOR CHEMICAL EXAMINATION OF IRRIGATION WATERS AND ALKALI SOILS

P. L. HIBBARD

University of California

Received for publication January 11, 1928

Brevity, completeness, and simplicity are the chief advantages of the method described in this paper. During several years of practical application, it has been found adequate and very satisfactory for characterizing and classifying waters and soils. A sufficiently exact quantitative determination of all the important ions in a water may be completed in fifteen minutes or less. No longer time is needed to analyze a soil extract, although it takes longer to prepare the extract. The accuracy of the determinations is not great, yet it is usually quite sufficient, and since ordinary samples of alkali soil are notoriously unrepresentative, high accuracy in the analysis seems unimportant.

The procedure described supplies a much more complete picture of the nature of the solution than any other brief method known to the writer.

Some of the tests are not precise enough to be of much value in determining the character of ordinary arable soils, since the concentration of the important plant nutrient ions in such soils is usually relatively low. Commonly, only when there is a considerable amount of sodium salts in a soil, is it spoken of as an alkali soil. However, in a technical sense, some may be true alkali soils, yet have only low concentrations of many ions usually found in considerable amounts in alkali soils.

Most of the tests are made on a water extract of the soil, consequently they are just as well adapted to examination of waters as to their normal composition and suitability for ordinary purposes, such as domestic use or irrigation. For this reason the procedure for examining an ordinary water will be described first, then the application of the tests to examination of soils will be given.

ESTIMATION OF AMOUNT OF PRECIPITATE BY TURBIDITY

A fair approximation of the amount of some precipitates may be had by comparison of the turbidity of the suspension with that of a standard known turbidity. For the comparison short 50-cc. glass cylinders known as "specimen tubes" are used. They are made of clear, colorless glass about 27 mm. diameter, and 82 mm. long with flat bottoms. The volume of solution usually taken for a test is 25 cc.

The amounts of precipitates produced in the unknown solution by suitable reagents are estimated by comparison with the precipitate from a known amount of the same ion in another tube, or by comparison with permanent standard turbidity tubes.

If the first method is to be used, it is most convenient to have known solutions of the appropriate salts containing exactly 1 mgm. of the desired ion in 1 cc. Suitable volumes of these standard solutions are measured into specimen tubes and precipitated at the same time, and in the same way, as the unknown. The procedure should be exactly the same in order to give good results. Then the amount of the ion in the unknown is found by comparison with the standard.

Permanent standard turbidity tubes are much more convenient. These are prepared by making a suspension of 100 mgm. of standard silica in 100 cc. of water, then diluting portions of it so that a scale of turbidities of 5, 10, 20, 30, 40, 60, 80, 100 mgm. in 100 cc. in separate tubes is obtained. These tubes are stoppered and labeled, and are then good for some months, whereas the standards produced by precipitating the ion itself, are not reliable after a few hours.

STANDARD SILICA FOR TURBIDITY

Treat white infusorial earth with HCl to remove the acid-soluble matter. Pour the acid suspension into a large volume of water. After allowing this to stand for 2 hours pour off the main portion of the liquid, retaining the material which has settled. Again mix with much water, let stand, and decant. When the very fine and the colloidal matter has been removed in this way, the remaining, somewhat coarser material is again stirred up in a considerable volume of water, allowed to stand only a few minutes, then decanted from the coarse particles which settle quickly. The medium fine material thus separated is allowed to settle, and is finally collected and dried. For use, the dry powder is weighed out and mixed with water in the comparison tubes so as to give concentrations of 5, 10, 20, etc., up to 100 mgm. in 100 cc. and the tubes are stoppered and labeled.

The standard suspensions are calibrated in terms of Ca, Mg, SO_4, etc., by direct comparison with known amounts of these ions, which have been precipitated by a definite standard procedure.

In order to estimate the amount of Ca, etc., in an unknown solution, it is precipitated by the standards and a reading made.

With the use of the SiO_2 prepared by the writer, table 1 was computed. A slightly different set of values may be needed for a different preparation of SiO_2.

MANNER OF COMPARING TURBIDITIES

The tubes containing the unknown and the standard turbidities are well shaken then held between the eye and a dark background several feet distant,

with the source of light above the background. In this way, one can make a more reliable reading than by looking directly through the tube toward the source of light, or than by trying to make the comparison by reflected light.

DETERMINATION OF THE PRINCIPAL IONS IN A WATER

Calcium. To about 25 cc. of the water in a "specimen tube," add 1 or 2 cc. saturated ammonium oxalate, and shake well. After a few minutes shake again and compare with the standard turbidity tube. If the water contains more than 100 p.p.m. Ca, take a smaller volume, 5 or 10 cc., and dilute it to the 25 cc. before adding ammonium oxalate.

Magnesium. To the tube containing the mixture tested for Ca add 0.2 to 0.5 gm. diatomaceous earth which has been washed with HCl, and then

TABLE 1

Standard silica for turbidity

SILICA READING	Ca	SO_4	Mg
	p.p.m.	*p.p.m.*	*p.p.m.*
5	7	20	3
10	15	35	7
15	20	50	10
20	27	60	13
25	33	70	17
30	40	80	20
40	53	100	27
50	67		34
60	80		43
70	93		52
80	106		64
90	120		80
100	133		115

with water, shake and pour on a 12½ cm. folded filter supported on a stemless funnel resting on another similar specimen tube. Do not wash. To the filtrate add sodium phosphate and ammonia to precipitate the Mg. Compare as with Ca.

Sulfate. Proceeding in the same manner as for Ca, precipitate SO_4 with 2.5 per cent $BaCl_2$. If the water is alkaline, add a few drops HCl. Compare as with Ca. In order to obtain satisfactory results for SO_4, the $BaCl_2$ should not be stronger than stated and the procedure should be exactly the same as in standardizing the turbidity tubes.

Carbonate (CO_3). Place 50 cc. of the water in a 12 cm. diameter porcelain dish, add a few drops 0.05 per cent phenolphthalein indicator and titrate to colorless with 0.02 N H_2SO_4 — cc. acid used $\times$ 24 = CO_3 in p.p.m. If there is no color with phenolphthalein, carbonate is absent.

Bicarbonate. After reading the burette for the carbonate titration, add 2 or 3 drops 0.02 per cent methyl orange indicator and continue running in the acid while stirring until the color becomes pale pink. From the total 0.02 N H_2SO_4 used, subtract twice the number of cubic centimeters used for CO_3; the remainder $\times$ 24.4 = HCO_3, p.p.m. in the water.

Chlorine. After the bicarbonate titration, add to the dish about 0.5 cc. K_2CrO_4 indicator (5 per cent) and titrate with silver nitrate (1 cc. = 1 mgm. Cl; 4.79 gm. $AgNO_3$ to 1 liter) till there is a faint permanent red precipitate. Number of cubic centimeters of $AgNO_3$ used $\times$ 20 = Cl, p.p.m. in the water.

Sodium. Calculate the reaction values of all the other principal ions. The sum of the reaction values of the anions minus the sum of the reaction values of the cations (Ca + Mg) equals the reaction value of sodium from which the amount of sodium may be calculated. The reaction value of any ion is found by multiplying the parts per million of the ion by its reaction coefficient. The reaction coefficient of any ion is found by dividing its valance by its reacting weight. Example—for Mg, $\frac{2}{24} = 0.083$; for SO_4, $\frac{2}{49} = 0.0208$, etc.

PROCEDURE FOR TESTING ALKALI SOILS

The soil should be dried and pulverized to pass a 2-mm. sieve. If the soil is very fine in texture, it is better to grind it much finer than 2 mm.

PREPARATION OF THE WATER EXTRACT

Into a 250-cc. bottle, place 200 cc. of distilled water, nearly free of CO_2, add 40 gm. of the pulverized soil, stopper the bottle and shake vigorously and frequently for an hour. Finally shake again, let stand half a minute, and pour off the liquid into a 24-cm. folded filter, retaining most of the solid matter in the bottle. If the first portion of the filtrate is not clear it may be returned to the filter.

ANALYSIS OF THE WATER EXTRACT

The water extract solution is analyzed just as described for ordinary water. The amounts found are multiplied by 5 to obtain the amount in the soil. In case the solution is dark colored, it may be necessary to use the indicators on a white plate by the spot method.

CONCENTRATIONS OF HYDROGEN ION

In most cases it is sufficient to add a few drops of the indicator to the insoluble residue in the bottle in which the water extract was prepared. First add phenolphthalein. If there is a pink color, the pH is above 8.4; if very red, it is probably 9.00, or higher. Precision in this range is usually not

important for alkali soils. If no pink appears, add cresol red. If this gives a color other than yellow, pH is estimated by comparison with buffer solutions or a printed color chart. If the color is yellow, another indicator must be used, ordinarily, brom cresol purple. This should be applied to the clear filtrate rather than to the soil suspension. If the pH is not in the range of brom cresol purple, methyl red, and then brom phenol blue are tried successively, all with the clear filtrate. The actual pH is found by comparison with buffers or a color chart. Details as to preparation and use of the indicator and buffer solutions are given by Clark (1).

ESTIMATION OF CALCIUM CARBONATE

After making the pH test on the insoluble residue in the bottle in which the soil extract was prepared, add 2 or 3 cc. of any strong acid, such as HCl. Effervescence indicates $CaCO_3$. The amount is estimated by the amount of gas set free. Less than 1 per cent $CaCO_3$ gives scarcely perceptible effervescence; 1–1.5 per cent, little; 1.5–3 per cent, very distinct; above 3 per cent, strong bubbling.

NITRATE

In some alkali soils, there is much nitrate. Some idea of the amount may be had by the diphenylamine or the carbazole test. Usually there is too much chlorine for success with the phenol-disulfonic acid method. In such cases, the Devarda method is reliable. In most cases, no test for nitrate is made.

PHOSPHATE

If desired, PO_4 in the water extract may be easily estimated by the molybdate blue method, originated by Deniges and fully described by Parker (2).

REFERENCES

(1) Clark, W. M. 1922 Determination of Hydrogen Ions. Baltimore, Md.

(2) Parker, F. W., and Fudge, J. F. 1927 Soil phosphorus studies: I. The colorimetric determination of organic and inorganic phosphorus in soil extracts and the soil solution. *Soil Sci.* 24: 109–117.

MANGANESE AS AN ACTIVE BASE IN THE SOIL

C. J. SCHOLLENBERGER

Ohio Agricultural Experiment Station

Received for publication February 10, 1928

During the course of some experiments intended to show the relation between surface and rate of decomposition of calcite particles in an acid Wooster silt loam, in which the soil and calcite mixtures were moistened and tightly packed in jars, and kept at 28°C. for 3 weeks, it was observed that the calcite particles were frequently stained brown. Qualitative tests demonstrated that the staining was due to a coating containing considerable manganese. At the same time the reaction of check mixtures to which no calcite had been added was found to have been changed after incubation in an unexpected manner toward the alkaline side. On the suspicion that there might be some connection between the development of active manganese and the change in reaction, several mixtures were prepared from the same lot of soil and treated in the same way. The reaction of 1:1 mixtures of the dry soil and water was determined by means of the quinhydrone electrode, and the exchangeable bases were determined by leaching with neutral ammonium acetate. The results are given in table 1.

From this, it will be seen that the only significant change produced by the treatment has been a very large increase in exchangeable manganese, together with a decrease in the acid reaction. The presence of starch has heightened these effects. The development of sufficient ammonia in the puddled mixtures to affect the reaction was considered as a possibility. Samples distilled with dilute alkali indicated no significant change in the apparent ammonia content. The data are considered to indicate that the increase in the percentage of the total base-absorbent capacity satisfied by the neutral salt-forming bases is the factor causing the change in reaction. This increase is due solely to the increase in exchangeable manganese. This is thought to have been caused by a biological reduction of higher oxides of manganese by soil organisms in the unsterilized mixtures; both of these kept moist had a pronounced butyric odor before drying, strongest in that to which the starch had been added.

Manganous hydroxide was prepared from $MnCl_2$ without the use of excess alkali and thoroughly washed with recently boiled water; an approximately fifth normal suspension of this was prepared and added in regulated amounts to 20-gm. portions of the dry soil, with sufficient water to equalize the volumes. After these mixtures had been allowed to stand for several days with occasional

stirring, the reaction was determined by means of the quinhydrone electrode. This experiment showed that the hydrogen-ion concentration of the mixtures was reduced in a regular manner by each succeeding increment of the manganese suspension, to practically the same exent as by the addition of an equivalent amount of calcium hydroxide. Each base added in amount equivalent to 4 tons $CaCO_3$ per acre raised the reaction to pH 7.5, but larger additions of manganese did not cause the alkaline reaction to increase significantly, whereas calcium hydroxide in amount equivalent to 6 tons $CaCO_3$ raised the reaction to pH 8.4.

Further evidence of the ease with which manganese tends to enter the exchangeable form was obtained in an experiment in which it was sought to

TABLE 1

Effect of treatments on the exchangeable bases and pH of a Wooster silt loam

	EXCHANGEABLE BASES, MGM. EQUIVALENTS PER 100 GM.							pH	BASE SATURATION
	Total absorptive capacity for NH_4	Al	Mn	Ca	Mg	K	Na		
									per cent
Original soil (not treated)............	9.9	0 2	0.2	0.6	0.1	0.2	0.2	4.7	13
Soil + water (treated).	9.9	0.1	1.6	0.6	0.1	0.2	0.2	5.0	27
Soil + 1 per cent starch + water (treated)..........	9.8	0.1	2.1	0.6	0.1	0.2	0.2	5.1	33

replace the bases in 4 soils with hydrogen by means of a tenth normal HCl extraction and washing. In the cases of all the neutral salt-forming bases except manganese the figures for exchanged base in the acid-extracted soils were reduced to comparative insignificance; in 3 of the 4 soils exchanged Mn was increased from practically nothing in the original soil to a significant figure in the extracted and washed soil, whereas in the fourth case there was only a small decrease. It is thought that this increase in exchangeable manganese was due to a reduction during the latter stages of the water-washing and air-drying processes, which together required about 3 days for completion.

It is evident that the ease with which manganese oxides in the soil are reduced, supplying an active base, introduces a complication into soil reaction studies which may be significant.

COLLOIDAL SOIL MATERIAL

P. L. GILE

Bureau of Chemistry and Soils, U. S. Department of Agriculture

Received for publication February 6, 1928

Within the last few years many investigations dealing with soil productivity, soil physics, soil classification, and the suitability of soils for engineering projects have appeared in which attention is focused particularly on the colloidal material. These papers form an important chapter in soil science. This chapter, however, is not so informative to the soil student as it might be, because the different authors vary considerably with respect to the soil material they regard as colloidal. So long as soil colloids are under investigation there can of course, be no unanimity of opinion regarding many features of this material, but it should be possible to have at this time a common understanding regarding what part of the soil is included in the term "colloid."

Some years ago opinions concerning what material in the soil is colloidal were especially diverse. It was variously held that the soil colloidal material is a substance of fixed composition, that it is material having certain properties, such as adsorption, to a definite degree, that it is material isolatable from the rest of the soil by this or that procedure. At the present time ideas concerning the colloidal soil material are much more uniform. Most soil investigators recognize that the colloidal material of the soil is very similar to the clay fraction obtained in a mechanical analysis and that it is quite variable in composition and properties (11, 3). Most chemists, however, would not classify all the material in the clay fraction as colloidal and they would classify as colloidal some material which does not occur in the clay fraction. There are a few chemists who apparently conceive of soil colloids in terms of chemical composition or reactivity rather than in terms of size. There is need therefore for adopting a clear definition of the material. Of course, any sharp definition of colloidal soil material must be more or less arbitrary, but as long as the arbitrariness is recognized, this should lead to no misconceptions; whereas a loose definition almost invariably gives rise to a confusion of tongues.

In response to this need for a clear-cut definition of soil colloids, Bouyoucos (6) has recently suggested that the colloidal soil material be defined as any soil material that will give heat of wetting in water; or, to quote,

> If the heat of wetting phenomena is accepted as a criterion for distinguishing colloids from noncolloids then soil colloids could be defined as any soil material dried at 110°C. that wil give heat of wetting in water irrespective of size of particles.

So far as simplicity is concerned, this definition leaves nothing to be desired and, as Dr. Bouyoucos points out, it is logical.

The mere fact that physical chemists have adopted small size of particle as the most satisfactory criterion for distinguishing colloids in the case of a wide variety of materials, does not, of course, exclude the use of other properties for distinguishing between colloids and noncolloids in the case of soil material. Heat of wetting, adsorption of vapors and ions, Brownian movement, and small size of particles are all characteristic of that soil material which practically all chemists would classify as colloidal. Also, soil material which all chemists would agree is noncolloidal possesses these properties either not at all or to an inappreciable degree. It seems logical, therefore, to adopt any one of these properties as a criterion for distinguishing between colloidal and noncolloidal soil material. In fact all these properties, as well as chemical composition, have been used for indicating the presence of colloidal material in soils.

However, a definition of soil colloids as "any soil material giving a heat of wetting" does not seem to be practicable, in spite of the fact that it is simple and reasonable. With this definition as a guide, it would not be possible to distinguish colloid from noncolloid in a mixture of these two classes of soil material. Any part of the soil, or the whole soil for that matter, would be classed as colloid according to this definition, if it had an appreciable heat of wetting; when as a mater of fact it might contain only a small quantity of colloid.

If the colloidal materials of different soils all had the same heat of wetting, a definition of soil colloids based solely on heat of wetting would be adequate for estimating the quantity of colloid in a soil, although it would not be a practicable definition to follow in isolating the colloidal material from a mixture. It is well recognized, however, and by Bouyoucos as fully as by any one, that the colloidal material of different soils may vary widely in specific heat of wetting (5, 1) as well as in practically all other properties (3, 9, 11). It is because of this variability in properties that ratio methods were adopted for estimating the quantity of colloids in soils both by the writer's associates and by Bouyoucos. In these methods the colloid content of a soil is obtained by comparing the adsorption or heat of wetting of the whole soil with that of a sample of colloid isolated from the same soil (9).

The inadequacy of a definition of soil colloids based primarily on heat of wetting seems to lie in the facts that the soil is a mixture and its different components cannot be recognized by means of heat of wetting. If the soil were a homogeneous material and it were a question of distinguishing between colloidal and noncolloidal soils, a definition such as has been proposed would be perfectly satisfactory, providing a lower limit for the heat of wetting characteristic of the colloidal class were adopted. But no apparatus or method is available for separating the soil components *according to* heat of wetting. It is, therefore, necessary to catch the colloidal material by some other criterion before examining it for heat of wetting.

The only methods available for recognizing or separating different components of the soil are the methods of mechanical, chemical, and microscopical or petrographic analyses. It seems, therefore, as though it would be expedient to use characteristics determined by these methods—particle size, chemical composition, and structure—as the primary criteria for distinguishing soil colloids. As a matter of fact, these criteria were used by the writer and his associates some time ago when investigating the estimation of soil colloids by adsorption methods (9). This investigation, of course, called for a description of the material which was being determined and at that time it seemed possible to define it in a recognizable manner only in terms of the older methods of soil examination. The definition drawn up at that time was suggested only as applying to that investigation and it is not now urged for general adoption. However, it may serve as a basis for discussion.

The colloidal soil material was described as comprising: all soil organic matter, inorganic material dispersable into particles less than a micron in diameter by a treatment that does not disintegrate distinctively mineral particles, and any undispersed material which microscopical observation shows is made up of particles less than 1μ in diameter. This is almost tantamount to defining soil colloids as all material in the soil except that which is present in hard, definitely formed particles more than 1μ in diameter. Although the definition may seem too inclusive, it divides the soil into two parts which are quite different in properties and in gross chemical composition. The noncolloidal part is without appreciable adsorptive capacity (2) or heat of wetting (1), and all of the colloidal part, as far as has been determined, has these and other colloidal properties to a comparatively marked degree. The definition is also in accord with the one in general use for distinguishing a wide variety of colloidal materials, inasmuch as the primary distinction is size of particle.

A definition of this kind fulfills one essential requirement, that of being practicable. By its use a pure colloidal fraction can be recognized without resort to other criteria and colloid can be identified when mixed with non-colloidal material. Various systems of mechanical analysis can be modified so as to yield a fraction containing only particles below 1μ in diameter and this fraction is, of course, pure colloid by definition. The pure colloid fraction, identified on the basis of particle size, may be further characterized by its specific heat of wetting, adsorptive capacity, or average size of particle. The fractions above colloidal size can be examined for undispersed colloidal material microscopically (8) and tested for colloid by adsorption or heat of wetting (9).

Probably the selection of 1μ as the diameter separating colloidal from noncolloidal particles will not meet with universal acceptance. In the case of many colloidal preparations $\frac{1}{2}$ to $\frac{1}{10}\mu$ has been taken as the upper colloidal limit. On the other hand, 1μ is about the lowest limit at which it is practicable to check a particle separation of soil material by microscopical observation. It might even be preferable to adopt 2μ as the limiting diameter of colloidal

soil particles. This limit has been used by some European investigators (4), and is the upper limit of the finest fraction in the English system of mechanical analysis. Moreover, a 2-μ fraction is obtained by sedimentation in considerably less time than is a 1-μ fraction. It is, of course, necessary to adopt some definite, arbitrary limit for colloidal size; but it is probably not of great moment whether this is placed at 1, 2, or 3μ, since nearly all of the soil material that is dispersable into particles below 1μ in diameter seems to be made up of particles very much smaller. Anderson and Mattson (3) showed that soil materials which were dispersed into particles below $\frac{3}{10}\mu$ in diameter by gentle rubbing in water with a trace of alkali contained particles averaging between 91 and 141 millimicrons, and Joseph (10) found that a soil fraction made up of particles below 2μ could all be dispersed into particles well below 1μ.

The inclusion of all soil organic matter in the colloidal class might be questioned. In the case of most soil types this is not a matter of much importance, since agricultural soils usually contain less than 5 per cent of organic matter and the greater part of this is dispersed into particles well below a micron by rubbing the soil in water containing a trace of ammonia. In the case of fibrous peat soils, however, the undispersable organic matter forms a considerable part of the whole soil material. This fibrous, partially decomposed material, is, of course, colloidal in structure and doubtless has a high heat of wetting and adsorptive capacity, and on these grounds should logically be classed as colloidal material. Its influence on the mechanical condition of the soil is however, widely different from that of the dispersable organic matter and more, like that of noncolloidal material. Probably such material should be designated as a special kind of colloidal soil material.

There is also some question as to how the nodular or pisolitic soil particles sometimes called "iron and manganese concretions" should be classified. Specific mention of these particles was not made in the preceding definition. These particles, which usually contain more iron and aluminum and occasionally much more manganese than the dispersable colloid, are abundant in certain highly weathered, lateritic soils of the Tropics and are present in lesser quantities in some of our southern soils. They are made up largely of amorphous or cryptocrystalline material, but may contain some easily identified quartz particles. Although they are far harder than aggregates of difficultly dispersable colloid, and usually have a characteristic form, they break down readily as compared with the ordinary soil minerals. So far as their influence on the structure of the soil is concerned, these particles should doubtless be classed as noncolloidal material; but in other respects they might be classed more logically as colloid. Under the ultramicroscope a considerable part of the material in a concretion is resolvable into particles or aggregates below 1μ in diameter. The adsorptive capacity of the concretions is appreciable as compared with that of the common soil minerals, although much less than that of the dispersable colloidal material. There are thus good grounds for classifyng material of this character either as colloidal or as noncolloidal. In whichever

class the material is thrown it should obviously be designated as a fairly distinct species of the class.

Possibly at present we should be chiefly concerned with the question of what soil components are to be included in the general class of soil colloids; but in the future it will doubtless be necessary to draw distinctions between different kinds of colloidal material that are present in the same soil. Mention has already been made of the need of distinguishing the fibrous from the dispersable organic matter and of segregating concretionary material from the other colloidal soil material. It may be advisable also to distinguish between colloidal material which is easily dispersed and that which requires drastic mechanical or chemical treatment for dispersion. There are some indications that the colloidal material which is not dispersed by rubbing in slightly alkaline water may differ appreciably in properties and chemical composition from that which is readily dispersed by this treatment. If future studies show that such is the case, a distinction should obviously be made between the two kinds of material. The difficultly dispersable colloidal material seems to be especially abundant in reddish, highly weathered soils, although small quantities are present in nearly all soils. The colloidal material which is readily dispersed by rubbing in water with a trace of alkali constitutes the larger part of the total colloidal material in most soils and is the material that has been the subject of most investigations. This seems to be fairly uniform material; at least, attempts to separate it into fractions that differ markedly in properties and composition have thus far met with little success (1, 7, 9). Many chemists, however, are of the opinion that this dispersable colloidal material contains definite aluminosilicic acids and salts in addition to the hydrous oxides of iron, alumina, etc. If this proves to be so, it will be necessary to distinguish still other kinds of colloidal soil constituents.

SUMMARY

It is recognized that the colloidal soil material might be simply and logically defined as "that material in the soil which has an appreciable capacity for adsorption or for evolution of heat on wetting." Such a definition is inadequate, however, for distinguishing between colloid and noncolloid in a mixture of these two classes of material, since soil materials cannot be separated according to their adsorptive or heat of wetting capacities.

The colloidal soil material has also been defined as including: all soil organic matter, inorganic material dispersable into particles less than 1μ in diameter by a treatment that does not disintegrate distinctively mineral particles, and any undispersed material which microscopical observation shows is made up of particles less than 1μ in diameter. A definition of this kind is practicable, since methods are available for separating or distinguishing soil constituents according to the characteristics specified; namely, chemical composition of the material and size and structure of particles. It is somewhat questionable whether

fibrous organic matter and iron concretions should be classed as colloid and whether the upper limit for the size of colloidal soil particles should be placed at 1μ or higher.

As studies of the colloidal soil material progress it will doubtless be necessary to distinguish between different kinds of colloidal material that may be present in the same soil.

REFERENCES

(1) Anderson, M. S. 1924 The heat of wetting of soil colloids. *Jour. Agr. Res.* 28: 927–935.

(2) Anderson, M. S., et al. 1922 Absorption by colloidal and noncolloidal soil constituents. U. S. Dept. Agr. Bul. 1122.

(3) Anderson, M. S., and Mattson, S. 1926 Properties of the colloidal soil material. U. S. Dept. Agr. Bul. 1452.

(4) Atterberg, A. 1914 Die Eigenschaften der Böden-körner und die Plastizität der Böden. *Kolloidchem.* 26 (2–3): 55–89.

(5) Bouyoucos, G. J. 1925 Heat of wetting as a new means of estimating the colloidal material in soils. *Soil Sci.* 19: 153–162.

(6) Bouyoucos, G. J. 1927 Defining soil colloids. *Science* 46: 353–354.

(7) Bradfield, R. 1923 The chemical nature of a colloidal clay. Missouri Agr. Exp. Sta. Res. Bul. 60.

(8) Fry, W. H. 1923 The microscopic estimation of colloids in soil separates. *Jour. Agr. Res.* 24: 879–883.

(9) Gile, P. L., et al. 1924 Estimation of colloidal material in soils by adsorption. U. S. Dept. Agr. Bul. 1193.

(10) Joseph, A. F. 1925 Clays as soil colloids. *Soil Sci.* 20: 89–94.

(11) Robinson, W. O., and Holmes, R. S. 1924 Chemical composition of soil colloids. U. S. Dept. Agr. Bul. 1311.

THE HYDROMETER METHOD FOR STUDYING SOILS

GEORGE JOHN BOUYOUCOS

Michigan Agricultural Experiment Station

Received for publication February 6, 1928

In previous communications the hydrometer method was proposed for making mechanical analysis of soils (1) and also for determining the colloidal content of soils (2, 3) in only a few minutes. Recently there have appeared certain criticisms from Joseph (4) and Keen (5) regarding this hydrometer method. These criticisms are based mostly on the hypotheses, that on account of the influence on the position of the hydrometer bulb by the varying concentration of the soil suspension columns, and also because the density of the soil suspension column varies from top to bottom, there must be serious error in the results. These points of criticism were taken into consideration at the outset and thoroughly investigated before the method was proposed. It was found, and so stated in the original publications, that neither the position of the hydrometer bulb, nor the varying density of the soil suspension column has any appreciable effect on the hydrometer reading. Indeed, it was stated that the hydrometer reading tends to give an average of all the densities from the top of the suspension column to the point where the soil settles out as a solid column. It is the object of this paper, therefore, to present experimental data bearing upon these points. The data contained below are representative of a large number of experiments. The procedure consisted of taking 50 gm. of soil, dispersing it by the dispersion machine, placing it in the special cylinders and allowing the suspension column to stand for varying periods of time, and taking a hydrometer reading of the undisturbed suspension column. Then the upper and lower halves of the column were siphoned off separately and their hydrometer readings determined. The two columns were then mixed together and the hydrometer reading was again taken.

	gm. per liter
1. Clay suspension column 4 days standing:	
Hydrometer reading of undisturbed suspension column	23.2
Hydrometer reading of upper half column (siphoned off)	20.0
Hydrometer reading of lower half column (siphoned off)	28.0
Average reading of upper and lower half columns	24.0
Hydrometer reading of the two columns mixed together again	23.1
2. Clay suspension column 2 hours standing:	
Hydrometer reading of undisturbed suspension column	28.12
Hydrometer reading of upper half column (siphoned off)	27.30

Hydrometer reading of lower half column (siphoned off)	30.10
Average reading of upper and lower columns	28.40
Hydrometer reading of the two columns mixed together again	28.20
3. Clay suspension column 15 minutes standing:	
Hydrometer reading of undisturbed soil column	36.17
Hydrometer reading of upper half column (siphoned off)	35.51
Hydrometer reading of lower half column (siphoned off)	38.94
Average reading of upper and lower columns	37.22
Hydrometer reading of the two columns mixed together again	36.83
4. Silt loam suspension column 4 days standing:	
Hydrometer reading of undisturbed suspension column	18.5
Hydrometer reading of upper half column (siphoned off)	17.1
Hydrometer reading of lower half column (siphoned off)	21.3
Average reading of upper and lower columns	19.2
Hydrometer reading of the two columns mixed together again	19.1
5. Silt loam suspension column 2 hours standing:	
Hydrometer reading of undisturbed column	24.3
Hydrometer reading of upper half column (siphoned off)	23.1
Hydrometer reading of lower half column (siphoned off)	27.2
Average reading of upper and lower columns	25.1
Hydrometer reading of the two columns mixed together again	24.9
6. Silt loam suspension 15 minutes standing:	
Hydrometer reading of undisturbed suspension column	29.4
Hydrometer reading of upper half column (siphoned off)	28.0
Hydrometer reading of lower half column (siphoned off)	31.9
Average reading of upper and lower half columns	29.9
Hydrometer reading of the two columns mixed together again	29.6
7. Loam suspension 24 hours standing:	
Hydrometer reading of undisturbed suspension column	10.5
Hydrometer reading of upper half column (siphoned off)	9.5
Hydrometer reading of lower half column (siphoned off)	12.5
Average reading of upper and lower columns	11.0
Hydrometer reading of the two columns mixed together again	10.8
8. Loam suspension 2 hours standing:	
Hydrometer reading of undisturbed suspension column	12.2
Hydrometer reading of upper half column (siphoned off)	11.5
Hydrometer reading of lower half column (siphoned off)	12.9
Average reading of upper and lower columns	12.2
Hydrometer reading of the two columns mixed together again	12.3
9. Loam suspension 15 minutes standing:	
Hydrometer reading of undisturbed suspension column	16.0
Hydrometer reading of upper half column (siphoned off)	14.8
Hydrometer reading of lower half column (siphoned off)	18.7
Average reading of upper and lower columns	16.7
Hydrometer reading of the two columns mixed together again	16.5

An examination of the above results shows clearly that in the case of soil suspensions that are rather dilute, the original hydrometer reading of the undisturbed suspension column is practically an exact average of the entire column. It will be seen that there is hardly any difference between the original reading and the average reading of the upper and lower columns. In the case of the more concentrated suspension, however, there is an error of about 1 gm.

between the original reading of the undisturbed column and the average reading of the upper and lower columns. Since the amount of soil taken in these experiments was 50 gm., an error of 1 gm. amounts to 2 per cent of the sample taken. On the other hand when it is considered that these concentrated suspensions contain about 70 to 80 per cent of material in suspension, the error of 2 per cent is practically negligible and relatively unimportant in the mechanical analysis of soils.

The foregoing results, therefore, refute the contentions or criticisms advanced by Joseph and Keen.

Joseph has also criticised the claim that the hydrometer method can be employed to determine the colloidal content of soil, on the basis that this colloidal determination includes clay plus silt. It must be stated at once, however, that the colloidal determination does not include all the silt that might exist in a soil, but only the finest silt, or that which approaches the clay size 0.005 mm. If the silt in a soil consists almost entirely of the coarser size, or 0.05 mm., the hydrometer method does not include it in its colloidal determination, and the percentage of colloids of this soil as determined by the hydrometer method will correspond very closely to the percentage of clay as determined by the mechanical analysis of the United States Bureau of Soils. On the other hand, if the silt of this soil is composed almost entirely of the finer size, the hydrometer method will include this in its colloidal determination, and, consequently, the percentage of colloids will be considerably larger than the percentage of clay indicated by the mechanical analysis method.

The hydrometer method includes in its colloidal determination the finest silt because this silt gives heat of wetting, as does clay, and the writer believes, as stated previously (3), that the standard that appears to be most logical to adopt for distinguishing colloidal soil material from non-colloidal soil material is some activity or energy manifestation of the soil material, such as heat of wetting, rather than an arbitrary size limit of particles. According to this view soil colloids have been defined as any soil material dried at 110°C. that will give heat of wetting in water irrespective of size of particles, provided the material is completely dispersed and the non-colloidal material is taken into account as previously described. It has been found experimentally that all soil material classified as clay and likewise the finer portion of the silt give heat of wetting. This would include soil particles as large as 0.008 mm., and even larger in some soils. Above the very fine silt there is hardly any measurable heat of wetting. All the organic matter that gives heat of wetting would also be classed as colloids.

If the basis of defining and distinguishing soil colloids from non-colloids is analyzed without bias it becomes obvious that it is a reasonable and logical basis. In the first place, it must be admitted that the present classification of soil particles is not absolute, that it is not based upon any fundamental grounds, and is merely a convenient arbitrary basis. In the second place, what is the use of classifying or dividing the soil particles into groups if these

groups cannot give us some definite knowledge? Now, if some of the silt has the same characteristics as the clay, why should it be put separately? Why should it not be classed with the clay? If we are willing to call clay a colloid because it has the characteristics of colloids, why not designate similarly that portion of the silt that has the characteristics of colloids? It might be argued that the fine silt does not possess the various characteristics, such as heat of wetting, plasticity, shrinkage, etc. to the same degree as the clay. But does the clay portion of all the different clay soils or the different particles of the same clay fraction possess these characteristics to the same degree? Certainly not. It is well known that some clays have very little plasticity and others have very high plasticity. Some silts have higher plasticity than some of the clays. In the next place, in soil research common sense is an asset where arbitrary rules fail. For instance, we say that silt has a range from 0.05 to 0.005 mm. and the clay from 0.005 mm. down. Now, if a soil has nearly all of its silt in the neighborhood of 0.005 mm. and another method like the hydrometer method classifies this silt as clay, why should such a method be considered wrong? As a matter of fact there may be no actual difference between this silt and clay. Finally, it must be remembered in comparing the hydrometer method with the mechanical analysis method, that the proportion of silt and clay in any given soil will depend upon the degree of dispersion and the presence of floculatory and defloculatory agents. If some soils are hard to disperse, the excess of silt over clay will be greater than if the same soils were easily dispersed. Now, the machine that is used in dispersing soils for the hydrometer method, is without question the most efficient means of dispersing soils known at present.

Because the results of the hydrometer method agree remarkably well with the results of the heat of wetting method, which takes into account the organic matter and other active materials, the hydrometer method tends to give more exact information regarding the active materials in soils than does the mechanical analysis.

Keen has also stated that the hydrometer method is essentially a qualitative method. This statement is not justified. The method is quantitative with only a reasonable degree of inaccuracy. That this is so is proved by the following facts: 1. If the column of soil suspension is siphoned off and evaporated to dryness the amount of residue is the same, within the experimental error, as that indicated by the hydrometer reading; 2. The results can be duplicated any number of times by any individual, if the directions are followed; 3. The error that Keen believed might arise on account of the different densities in the column, is either non-existent or so small as to be unimportant.

There is really more in the hydrometer method than is revealed from purely theoretical considerations. Indeed, as will be shown in a later paper, if we divide the soil particles into three groups—sand, silt, and clay or colloids—the hydrometer method can make this separation or analysis in 15 minutes. The results obtained show that the percentage of the combined sands, as

indicated by the hydrometer method, agrees perfectly with the percentage of the combined sands as obtained by the United States Bureau of Soils mechanical analysis method. This was true in over thirty different soils investigated. As to the silt and clay percentages, the two methods agreed well in some soils, but disagreed in others, the reasons for which were partly discussed above. It has also been found that the hydrometer method can be used to make a detailed mechanical analysis of soils. A complete or detailed mechanical analysis of more than ten soils can be made in one day and such analysis will have a greater number of divisions of soil particles than is obtained by the present mechanical methods.

It is believed after very thorough investigation, that the hydrometer method is a rather remarkable and unique means of studying soils quickly, simply, and accurately.

REFERENCES

(1) Bouyoucos, G. J. 1927 The hydrometer as a new method for the mechanical analysis of soils. *Soil Sci.* 23: 343–352.

(2) Bouyoucos, G. J. 1927 The hydrometer as a new and rapid method for determining the colloidal content of soils. *Soil Sci.* 23: 319–330.

(3) Bouyoucos, G. J. 1927 Directions for determining the colloidal material in soils by the hydrometer method. *Science* 66: 16–17.

(4) Joseph, A. F. 1927 The determination of soil colloids. *Soil Sci.* 24: 271–274.

(5) Keen, B. A. 1928 Soil mechanics and physics. *Soil Sci* 25 9–20.

THE CROP-PRODUCING POWER OF LIMITED QUANTITIES OF "ESSENTIAL" PLANT NUTRIENT

CHARLES HARTMAN, Jr. and WILBUR L. POWERS[1]

Oregon Agricultural Experiment Station

Received for publication February 2, 1928

In culture solutions lacking one of the "essential" plant nutrients, a study was made of an initial increment and succeeding increments of the lacking essential element. The crop-producing power of limited quantities of essential nutrients has been determined for the conditions of the experiment and is reported herein.

It was further sought to determine just what effect the total absence of an element and the addition of succeeding increments of this element (in parts per million) play in the nutrition and growth of a crop—whether there is a direct or indirect effect from this element, whether it can be replaced partially or completely by other elements—and its consequent bearing as a limiting factor in crop production.

By obtaining such relative values in parts per million of the essential elements that are necessary for the proper nutrition and growth of plants and by comparison with the available nutrients of soils and their solutions it is hoped that the choice of crops and the rate, application, and time of fertilizing may be better understood.

PLAN OF INVESTIGATION

Wheat seedlings were grown in complete nutrient solution lacking nitrogen, and the effects were studied of the addition of an initial increment of nitrogen and succeeding increments in parts per million until a sufficient quantity had been added for the proper nutrition of the plant. As 0.9 liter was used in a culture jar, 0.9 mgm. of nitrate nitrogen was contained in each part per million supplied.

Like studies were made with the five other essential nutrients including the anions sulfate and phosphate, and the cations calcium, magnesium, and potassium. The experiments were conducted between September, 1924 and June, 1925.

In tables 1 through 6 are given the average yields with each essential element, in an endeavor to show the increasing yield for each additional increment of the limiting element, and to indicate the concentration needed.

[1] Contribution from the Soil Department, released with the approval of the Director.

CULTURAL METHODS

Grimm alfalfa and Federation wheat were the varieties of seed selected. Ten times the needed number of seeds were germinated in the usual way. The usual care during growth and in their selection for experimental use was observed. The seedlings were allowed to grow until the fourth leaf was well out, and then were transplanted to the culture solution.

The plants were grown in quart mason jars which held approximately 900 cc. The jars were wrapped with heavy brown wrapping paper to exclude light from the plant roots. Five plants were grown in each jar.

The plants were grown in the college greenhouses where external conditions could be controlled. During the winter months and dark cloudy days, the length of daylight and the intensity of light were increased by the use of a 1000-candle power electric nitrogen bulb to which the plants readily responded.

The pH value of all the solutions was made up between 5.6 and 5.8. Plants were grown in the same solution for the entire duration of the experiment. The pH value of the solution was determined at intervals, but no radical changes were found. The solutions were buffered by the use of mono- and dibasic phosphates.

No set period of growth was maintained, the length of trial depending upon the differences shown in the cultures of different concentrations of the ion under observation. When these differences were significant the plants were removed, washed, and rewashed in distilled water, and the dry weights of roots and tops determined.

NITROGEN

In discussing the nutritive and physiological importance that nitrogen plays in plant growth we deal with a nutrient whose functions are many-fold. The lack of nitrogen causes a long, fibrous root system, while the tops appear chlorotic, turn yellow, and die. Without nitrogen, plants are unable to mature and develop seed. Where copious quantities of nitrogen are present the root system is much smaller in proportion to the tops, the top growth becoming dark green, succulent, rank, and sappy.

Nitrogen is generally taken into the plant in the form of nitrate, yet it is well known that nitrogen may be assimilated by some plants in the form of ammonia. When there is a deficiency of nitrogen, older mature leaves may release the nitrogen for translocation and further use in the development of other plant parts.

The plants were grown in various concentrations, each series consisting of six jars of five plants each. Nitrogen was supplied from a liter solution of calcium nitrate.

Approximately 1450 p.p.m. of salts were used to effect an otherwise physiologically balanced solution. $MgSO_4$, K_2HPO_4, KH_2PO_4, and $CaSO_4$ were the salts employed.

The pH value changed slightly during the growth of the plants, tending toward neutrality, 1 cc. tenth normal acetic acid being added to each jar during their growth.

The wheat plants were grown to maturity, observations being taken from time to time on the growth and general appearance of the plants. The results of their average growth in each series on the dry weight basis are given in table 1.

Conclusions

That the growth of wheat plants responds to successive increments of nitrogen is conclusively shown. Little growth can be expected where nitrogen is deficient.

Under the conditions provided, 64 p.p.m. of nitrogen was not sufficient for the proper formation and maturity of seed. The lack of nitrogen develops an extensive fibrous root system which becomes less apparent as nitrogen is added, the ratio of tops to roots widening at each increment of nitrogen.

TABLE 1

Average growth of wheat in nitrogen series, on a dry weight basis

NITROGEN SERIES	CALCIUM NITRATE	AVERAGE DRY WEIGHT OF TOPS	AVERAGE DRY WEIGHT OF ENTIRE PLANT	RATIO TOPS TO ROOTS
	p.p.m.	*gm.*	*gm.*	
N-A	0	0.255	0.43	1:0.69
N-B	2	0.520	0.74	1:0.42
N-C	4	0.730	1.05	1:0.44
N-D	8	0.860	1.34	1:0.56
N-E	16	1.380	2.05	1:0.49
N-F	32	3.160	4.09	1:0.29
N-G	64	3.780	4.16	1:0.22

The lack of nitrogen causes a chlorotic, sickly looking plant. Successive leaves develop, and each set becomes less vigorous as the others die, until the plant itself succumbs. Such a procedure might indicate that wheat plants may have the power to transfer nitrogen from the dying leaves to the growing parts of the plant for reuse.

For each increment of nitrogen, the yield is increased, but the increases become successively smaller. This is in accordance with the law of diminishing returns. Up to approximately 30 p.p.m. a decided decrease in yield is apparent for each additional part per million added, indicating that this is the economic concentration for the conditions at hand.

CALCIUM

Calcium is an essential plant-food element, its presence being necessary for the proper development of all the higher forms of plant life. Large amounts of calcium produce a strong, healthy looking plant with good root development

whereas limited amounts greatly reduce the root development, retarding seriously the growth of the plant.

The plants were grown as previously outlined. Calcium nitrate was used as the source of calcium.

The results of the average growth in each series on the dry weight basis are given in table 2.

Conclusions

1. A greater concentration of calcium is necessary for the first substantial increase in growth than for any other of the essential elements studied.

2. A deficiency of calcium greatly hinders the root development of alfalfa plants, the ratio of tops to roots narrowing at each successive increment of calcium.

3. Large amounts of calcium cause a stocky, healthy looking plant with a stout, thrifty root.

TABLE 2

Average growth of alfalfa in calcium series, on the dry weight basis

CALCIUM SERIES	CALCIUM NITRATE	AVERAGE DRY WEIGHT OF TOPS	AVERAGE DRY WEIGHT OF ENTIRE PLANT	RATIO TOPS TO ROOTS
	p.p.m.	*gm.*	*gm.*	
Ca-A	0.0	0.025	0.026	1:0.04
Ca-B	1.5	0.025	0.029	1:0.16
Ca-C	3.0	0.025	0.029	1:0.16
Ca-D	6.0	0.059	0.067	1:0.14
Ca-E	12.0	0.630	0.850	1:0.35
Ca-F	24.0	0.780	1.090	1:0.35
Ca-G	32.0	0.995	1.350	1:0.35
Ca-H	64.0	0.950	1.340	1:0.41

4. Each increment from 6 to 12 p.p.m. produced the greatest yield per part per million, whereas increments added after 32 p.p.m. did not further the growth to any extent.

5. The presence of large quantities of magnesium in proportion to the calcium present up to and including 6 p.p.m. is probably a limiting factor in plant growth. Other portions of the experiment show that a wide ratio of calcium and magnesium can exist, little harm being done if an adequate amount of calcium is present.

MAGNESIUM

Although magnesium plays a rôle in the formation of chlorophyll it appears later to move to the seed, being present in large quantities in seeds of an oily nature. Magnesium salts may become toxic to plants where there is a deficiency of calcium, but that plants require a definite calcium-magnesium ratio in their food is doubtful.

That magnesium is an essential element is substantiated by the experiment on the behavior of the plants grown in the absence of it.

The results of the average growth in each series on the dry weight basis are given in table 3.

Conclusions

Where there was a total lack of magnesium, the leaves became chlorotic, wilted, and dropped off, leaving the bare stems. This was noticeable to a slight degree where 2 p.p.m. of magnesium was present. A narrowing of the ratio of the tops to roots was evident with increasing parts per million.

TABLE 3

Average growth in magnesium series, on the dry weight basis

MAGNESIUM SERIES	MAGNESIUM	AVERAGE DRY WEIGHT OF TOPS	AVERAGE DRY WEIGHT OF ENTIRE PLANT	RATIO TOPS TO ROOTS
	p.p.m.	*gm.*	*gm.*	
Mg-A	0	0.170	0.220	1:290
Mg-B	2	0.610	0.830	1:360
Mg-C	4	0.650	0.886	1:360
Mg-D	8	0.670	0.920	1:370
Mg-E	16	0.655	0.920	1:405
Mg-F	32	0 710	1.040	1:460
Mg-G	64	0.820	1.150	1:400
Mg-H	128	0.910	1.350	1:480

TABLE 4

Average growth of potassium series on the dry weight basis

POTASSIUM SERIES	POTASSIUM	AVERAGE DRY WEIGHT OF TOPS	AVERAGE DRY WEIGHT OF ENTIRE PLANT	RATIO TOPS TO ROOTS
	p.p.m.	*gm.*	*gm.*	
K-A	0	0.240	0.320	1:330
K-B	3	0.610	0.890	1:460
K-C	6	0.700	1.040	1:486
K-D	12	0.735	1.080	1:483
K-E	24	0.880	1.240	1:410
K-F	48	0.880	1.210	1:376
K-G	96	0.800	1.115	1:390
K-H	144	0.920	1.270	1:380

Two parts per million gave by far the largest increase per increment, with a slight increase in yield per additional increment up to 128 p.p.m.

There was no noticeable magnesium injury with 128 p.p.m. of magnesium, the nutrient solution containing 240 p.p.m. of calcium. On the other hand in the calcium experiment, there were 136 p.p.m. of magnesium and no substantial growth occurred with 8 p.p.m. of calcium. This lack of growth may be either from the lack of calcium or from magnesium injury.

POTASSIUM

Potassium is an essential element whose physiological rôle in plant nutrition has probably a relation to the development of the starchy material of plants, the leaf, the stock, and the starchy portion of the seed.

A deficiency of potassium may be noted from the appearance of the leaves, which develop a poor, dull color, the stem becomes weak and does not stand up well, the seed appears small and shriveled. The vigor of the plant is impaired and it readily succumbs to disease.

The results of the average growth of each series are given in table 4.

TABLE 5

Average growth of phosphorus series, on the dry weight basis

PHOSPHORUS SERIES	PHOSPHORUS	AVERAGE DRY WEIGHT OF TOPS	AVERAGE DRY WEIGHT OF ENTIRE PLANT	RATIO TOPS TO ROOTS
	p.p.m.	*gm.*	*gm.*	
P–A	0	0.032	0.081	1:1.530
P–B	2	0.470	0.760	1:0.620
P–C	4	0.730	1.040	1:0.425
P–D	8	0.880	1.190	1:0.350
P–E	16	0.800	1.120	1:0.400
P–F	32	0.810	1.110	1:0.370
P–G	64	0.820	1.150	1:0.400
P–H	128	1.280	1.760	1:0.375

TABLE 6

Average growth of sulfur series on the dry weight basis

SULFUR SERIES	SULFUR	AVERAGE DRY WEIGHT OF TOPS	AVERAGE DRY WEIGHT OF ENTIRE PLANT	RATIO TOPS TO ROOTS
	p.p.m.	*gm.*	*gm.*	
S–A	0	0.51	0.89	1:0.745
S–B	5	0.92	1.64	1:0.780
S–C	10	1.02	1.80	1:0.770
S–D	15	1.75	2.60	1:0.490
S–E	20	1.06	1.88	1:0.770
S–F	25	0.97	1.74	1:0.790
S–G	30	1.06	1.84	1:0.740
S–H	60	0.94	1.65	1:0.760

Conclusions

Without potassium, plant growth was seriously impaired. The leaves took on a dull color, the stems were small and not erect.

An initial increment of 3 p.p.m. increased the yield enormously and with each additional increment a slight increase in yield was noted.

PHOSPHORUS

Although phosphorus promotes root growth in a remarkable way during the early growth of the plant, it hastens the ripening processes and forms a portion of the seed in the last stages of plant growth.

The close connection between cell division and phosphorus supply may account for the large amount of phosphorus compounds stored up in the seed for the use of the young plant and also for the relatively large amounts of phosphorus that are used during the early growth of the plant.

The results of the average growth in each series on the dry weight basis are given in table 5.

Conclusions

Where there was a total lack of phosphorus there was an entire lack of growth of tops while the roots grew but little, the weight of the roots being more than the tops.

As phosphorus was added, there was a slow but continual increase in yield from 4 to 128 p.p.m., the greatest increase again occurring with the first two additions of 2 and 4 p.p.m.

The presence of phosphorus increases the development of the roots, which become large and fibrous. The ratio of tops to roots showed a tendency to widen as phosphorus was supplied.

SULFUR

Sulfur is an essential food constituent and is most effective in producing increases in yield in crops of heavy protein content.

The results of the average growth in each series on the dry weight basis are given in table 6.

Conclusions

Alfalfa plants made a larger growth where sulfur was entirely lacking than with lack of any other element studied.

Upon the addition of each increment of sulfur up to 15 p.p.m. there was a decided beneficial effect, after which there was a slight tendency toward a decrease in yield, the yield with 60 p.p.m. approximating that obtained with 10 p.p.m.

SUMMARY

These studies seem to indicate the optimum concentration needed during the earlier stages of growth and also the crop producing power of each milligram of so-called "essential" element, for the conditions of the experiment. Nitrate ion effected by far the highest yield of dry matter per milligram while the formation of dry matter per milligram magnesium ion was comparatively low. In another report the concentrations needed in the soil solution for optimum growth are indicated to be at least as high as here suggested in the case of sulfate and calcium ions.

REPLACEABLE BASES IN SOME SOILS FROM ARID AND HUMID REGIONS

MOYER D. THOMAS

Utah Agricultural Experiment Station

Received for publication January 30, 1928

It is well established that different replaceable bases modify profoundly the physical properties of a soil and it seemed probable that a study of the question by means of the vapor pressure-moisture function would throw light on the nature of these changes. Preliminary to this investigation a group of heavy clays were collected from widely separated localities and treated to exchange their replaceable bases for a single base. In the course of this work, considerable chemical data were obtained which bring out some characteristic base exchange properties and solubility effects of neutral and alkaline soils, confirming and extending the conclusions recently summarized by Kelley (3, 4).

MATERIALS

The soils studied included seven natural heavy clays; a mechanical separate with particles smaller than one micron radius, prepared from one of the clays; and a natural colloidal silicate of the type of Bentonite. The description of these materials follows.

1. Trenton Clay (T-1). This is a heavy calcareous clay from Cache Valley, Utah, which has already been described.
2. No. 1170. A moderately heavy non-calcareous clay from Cache Valley, Utah. This sample is a surface soil low in organic matter and impregnated with soluble salts to the extent of about 1 per cent. It is designated Ballard Clay.
3. No. 1170-A. A mechanical separate from preceding soil, with particles smaller than one micron radius.
4. No. 1171. Subsoil to No. 1170. Depth 10 to 15 inches. This sample represents a concentration layer in the soil profile for lime and colloidal material. It contains 1.15 per cent of carbonate CO_2, and about 2 per cent of soluble salts.
5. No. 1286. A moderately heavy clay supplied by W. P. Kelley of California. This sample belongs to the Ramona series and has been extensively studied by Kelley under laboratory No. 431 (3).
6. No. 1293. A light subsoil clay of the Dayton series supplied by R. E. Stephenson of Oregon.
7. No. 1294. Very heavy Oktibbeha clay supplied by F. W. Parker of Alabama. This sample is similar to but not identical with the samples studied by Parker (5).
8. No. 1295. Putnam subsoil supplied by Richard Bradfield of Missouri. Sample is similar to but not identical with the sample studied by Bradfield (1).
9. No. 1296. Colloidal mineral silicate from Marysvale, Utah. This material had been deposited in brine and contained about 2.5 per cent of soluble salt, principally sodium sulfate and chloride. As indicated in table 7, this mineral is a rather pure specimen of magnesium

aluminum silicate having the approximate composition $(MgO)\cdot(Al_2O_3)\cdot(5SiO_2)\cdot(2H_2O)$. The mineral contains only small amounts of iron and calcium, though large crystals of gypsum were mixed with it in the natural state. Part of the magnesium had been replaced by sodium in the mineral as found.

All these samples were very low in organic matter except Soil No. 1286, which had a dark gray color. Mechanical analyses are given in a paper to be published later.[1]

TABLE 1

Analyses of successive extracts from three soils*

Ninety to ninety-five per cent of the water added was removed before the subsequent addition was made.

	RATIO OF SOIL TO WATER	Cl	SO_4	CO_3	HCO_3	SiO_2	Ca	Mg	Na	K	TOTAL	TOTAL BY EVAPORATION
						Trenton clay						
1	1–5	120	294	0	915	...	32	13	478	60	1,912	1,865
2	1–8.3	20	18	95	885	27	28	20	350	60	1,503	1,590
3	1–8.3	12	.....	40	722	50	27	17	158	70	1,096	1,057
4	1–8.3	12	.....	20	650	42	52	39	78	80	973	850
5	1–8.3	15	.....	Trace	710	20	52	35	29	70	931	825
6	1–8.3	18	.....	0	720	25	63	34	16	64	940	836
Total.....		197	312	155	4,602	164	254	158	1,109	404	7,355	7,023
						Soil 1170						
1	1–5	1,950	1,900	0	595	...	12	17	2,160	115	6,749	.....
2	1–6	197	225	16	980	...	18	5	550	19	2,010	.....
3	1–6	20	63	6	730	...	27	5	315	18	1,184	.....
4	1–6	20	53	3	540	...	18	5	220	12	871	.....
5	1–6	.....	53	0	490	...	18	7	230	16	814	.....
Total.....		2,187	2,294	25	3,335	...	93	39	3,475	180	11,628	.....
						Soil 1171						
1	1–6.5	3,620	4,530	75	900	...	94	57	4,700	180	14,156	.....
2	1–8	355	510	150	1,040	...	53	17	960	31	3,096	......
3	1–8	41	82	96	1,060	...	23	11	435	46	1,794	.....
4	1–8	12	65	106	940	...	25	14	450	18	1,630	.....
5	1–8	12	65	86	730	...	18	12	420	22	1,365	.....
6	1–8	.....	130	33	900	...	9	10	400	22	1,504	.....
Total.....		4,040	5,382	546	5,570	...	222	121	7,365	319	23,545	.....

* In p.p.m. of dry soil.

EXPERIMENTAL

Soils T-1, 1170, and 1171 were first washed by shaking with a measured volume of water and filtering on the Pasteur-Chamberland filters, 90 to 95 per

[1] Thomas, M. D. Replaceable bases and the dispersion of soil in mechanical analysis. Soon to appear in *Soil Science*.

cent of the water added being thus removed. The process was repeated several times with fresh portions of water and the successive filtrates were

TABLE 2

Partial analyses of the final wash liquids obtained when the soluble salt was removed from the soil preparations treated with sodium chloride or potassium chloride

SOIL	SALT ADDED	WEIGHT OF SOIL	VOLUME OF WASH LIQUID	CONCENTRATION IN WATER OF			
				Cl	OH	CO_3	HCO_3
		gm.	*cc.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Trenton clay	NaCl	75	700	426	47	504	0
			825	99	0	120	220
			400	30	0	78	183
			.....	4	0	1	129
Trenton clay	KCl	75	700	199	0	182	97
			500	57	0	60	122
			300	.....	0	24	120
1171	NaCl	75	750	495	0	48	275
			900	39	0	78	82
1171	KCl	75	900	43	0	30	335
			500	14	0	15	140
1286	NaCl	60	500	3,410	0	0	183
			440	190	0	0	36
			500	35	0	0	30
1286	KCl	60	550	120	0	0	55
			550	11	0	0	61
1294	NaCl	75	500	595	0	0	24
			750	107	0	0	24
			1,500	14	0	0	30
			900	.....	0	0	30
1294	KCl	75	850	35	0	0	18
			600	7	0	0	24
1296	NaCl	50	1,250	1,340	0	3	55
			470	110	0	Trace	97
			400	42	0	0	67
1296	KCl	50	750	370	0	4	43
			600	25	0	0	43

analyzed. The results are given in table 1. All the soils were then treated with normal solutions of the chlorides of sodium, potassium, ammonium, and calcium, and in some cases, of magnesium and aluminum, and also with 0.05

N HCl, as follows: 50 to 75 gm. of the soil were digested for several hours or over night with 250 cc. of salt solution, which was then decanted as completely as possible on a filter paper and replaced with fresh liquid, the process being repeated until about 2 liters of solution had been used. This treatment is more drastic than that recommended by Kelley (3). The soluble salt was then washed out and when its concentration was low, as indicated by the

TABLE 3

Partial analyses of the final wash liquids obtained when the soluble salt was removed from the soil preparations treated with calcium chloride or ammonium chloride

SOIL	SALT ADDED	WEIGHT OF SOIL	VOLUME OF WASH LIQUID	CONCENTRATION IN WATER OF		
				Cl	CO_3	HCO_3
		gm.	*cc.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Trenton clay	NH_4Cl	70	850	220	84	98
			750	17	12	94
			500	8	18	85
Trenton clay	$CaCl_2$	75	650	185	0	55
			600	32	4	60
			500	10	3	40
1171	$CaCl_2$	75	750	246	0	70
			650	57	0	67
			300	21	0	42
1286	NH_4Cl	60	530	142	0	61
			650	11	0	61
1294	$CaCl_2$	75	500	171	0	12
			500	14	0	12
1294	NH_4Cl	75	850	107	0	24
			750	10	0	24
1296	NH_4Cl	50	820	85	0	24
			500	28	0	27
1296	$CaCl_2$	50	800	114	0	24
			500	21	0	30

tendency of the soil to disperse, the washing process was continued by successively shaking with water and filtering on the Pasteur-Chamberland filter as described above until the chlorine was reduced to about 10 p.p.m. in the last filtrate. Titrations were also made for alkalinity in the extracts. Representative data from these titrations are presented in tables 2 and 3, the alkalinity being expressed as carbonate and bicarbonate.

It should be pointed out that the data in tables 2 and 3 are not strictly

comparable with those in table 1 because the latter give the salt concentration in the soils and the former, the concentration of the solutions.

The salt solutions which were decanted from the soil were analyzed for as many of the dissolved bases as seemed practical. No attempt was made to determine potassium in the sodium chloride solution or sodium in the potassium chloride solution, nor to determine either of the alkalies in the magnesium solution. Samples of the washed ammonium chloride treated soil were distilled with NaOH to determine the amount of NH_4 taken up. Carbonate CO_2 analyses were made on the calcareous soils and the replaceable calcium and magnesium values corrected by subtracting the amount of $CaCO_3$ dissolved. These data are summarized in tables 4 and 5, both as percentages and as milli-equivalents of the elements per kilo of soil.

Hydrogen-ion concentration measurements made by means of the quinhydrone electrode on most of the samples are presented in table 6.

Finally complete chemical analyses of the six different samples of No. 1296 are given in table 7.

DISCUSSION OF DATA

Table 1 indicates that when the excess of soluble salt is removed from the three Utah soils, subsequent filtrates have a marked alkalinity, calculated as carbonate and bicarbonate, although part may be due to soluble silicates. The latter is determined only in the case of the Trenton Clay and is noticeably low. The two alkali Ballard soils, 1170 and 1171, show a nearly constant solubility of sodium on a very high level of concentration as compared with the solubility of the other bases, whereas the calcareous Trenton clay, which contains only a small amount of replaceable sodium, loses this element rapidly from the system. Evidently it would be impracticable to remove the sodium from the Ballard soils by simple leaching, and a chemical treatment would be necessary to assist in the reclamation of such land.

The preponderance of acid carbonate over the normal salt in these leachings may be due in part to the fact that no attempt was made to remove carbon dioxide from the soil sample and the distilled water used. This point is emphasized because in table 2, one of the wash liquids from the NaCl-treated Trenton clay was so highly alkaline that all the CO_2 of the system was used up and sodium hydroxide appeared in the filtrate. It can be inferred, therefore, that at least part of the alkalinity is caused by direct hydrolysis of the sodium silicate complex, though it is probable that there is also a metathetical reaction between this substance or the products of its hydrolysis and $CaCO_3$ to give Na_2CO_3. The KCl-treated sample of Trenton clay seems to behave in a similar manner, but no free hydroxide was encountered.

Tables 1, 2, and 3 show that the quantity of alkalinity attending the leaching of the local soils is much greater than with any of the others, though in the case of the calcium treatment it is quite low, even in Trenton clay. The NH_4Cl digestion is followed by considerably less hydrolysis than either the KCl or

TABLE 4

Analyses of replaceable bases removed by solutions of different salts and dilute hydrochloric acid

SALT TREATMENT	ANIONS DISSOLVED		CATIONS DISOLVED							REPLACEABLE AND SILICATE BASES						NH₄ ABSORBED
	SiO_2	CO_2	R_2O_3	Ca		Mg		Na	K	Ca	Mg	Na	K	Total	Less $CaSiO_3$	
				Total	Less $CaCO_3$	Total	Less $MgCO_3$									
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*milliequivalents per kilo*						
Trenton clay—carbonate CO_2 = 15.55 per cent																
N NH_4Cl (a)	....	1.00	.....	0.865	0.100	0.228	0.150	......	......	50	125	...	..	...	...	...
N NH_4Cl (b)	....	0.60	.....	0.455	0.100	0.252	0.150	0.0110	0.0655	50	125	4	17	196	...	50
N NaCl	....	0.20	.....	0.220	0.040	0.145	0.145	......	......	20	121	...	..	...	...	...
N KCl	....	0.15	.....	0.250	0.110	0.156	0.156	......	......	55	130	...	..	...	...	...
N $CaCl_2$	....	0	.....	.....	.....	0.153	0.153	0.0037	0.0420	...	127	1.5	11	...	...	...
N $MgCl_2$	....	....	.....	0.031	0.031	.....	.....	......	......	15	...	...	..	...	...	...
Soil 1170—carbonate CO_2—(trace)																
0.05 *N* HCl	....	....	1.09	0.37	.....	0.230	.....	0.240	0.164	185	189	105	42	...	...	...
N NH_4Cl	0.24	....	....	0.35	.....	0.160	.....	0.250	0.150	175	131	109	38	453	372	240
N NaCl	....	....	.....	0.20	.....	0.064	.....	......	......	100	36	(147)		238	...	...
N KCl	0.09	....	.....	0.20	.....	0.066	.....	......	......	100	54	(147)		301	271	...
N $CaCl_2$	....	....	.....	.....	.....	0.031	.....	0.125	0.090	...	26	55	23	...	...	...
Soil 1170-A—carbonate CO_2 = 0.02 per cent																
0.05 *N* HCl	....	....	0.63	0.530	.....	0.370	.....	0.104	0.280	265	304	45	72	...	...	...
N NH_4Cl	0.57	....	.....	0.500	.....	0.210	.....	0.090	0.315	250	172	39	81	542	352	325
N NaCl	....	....	.....	0.405	.....	0.124	.....	......	......	203	102	(120)		425	...	...
N KCl	0.15	....	.....	0.400	.....	0.150	.....	......	......	200	124	(120)		444	394	...
N $CaCl_2$	....	....	.....	.....	.....	0.090	.....	0.088	0.195	...	74	38	50	...	...	...
N $AlCl_3$	....	....	.....	0.650	.....	0.307	.....	0.115	0.260	325	252	50	67	...	...	...

Soil 1171—carbonate CO_2 = 1.15 per cent

0.05 *N* HCl	....	1.06	0.113	1.170	0.22	0.392	.....	0.180	0.197	110	322	78	50	...	...	...
N NH_4Cl	0.62	0.95	.....	1.210	0.35	0.286	.....	0.180	0.300	175	235	78	77	565	360	350
N NaCl	....	0.15	....	0.395	0.26	0.085	.....	......	......	130	70	(155)		355	...	...
N KCl	0.19	0.16	.....	0.420	0.27	0.113	.....	......	......	135	93	(155)		383	320	...
N $CaCl_2$	....	0	.....	.....	.....	0.074	.....	0.128	204	...	61	56	52	...	...	...
N NH_4Cl*	....	....	.....	.....	0	.....	0	0.289	331	0	0	125	85	210	...	...

* Analysis of Kelley and Brown (4); sample No. 7070; soluble salt not removed before treatment.

TABLE 5

Analyses of replaceable bases removed by solutions of different salts and dilute hydrochloric acid

SALT TREATMENT	BASES DISSOLVED						REPLACEABLE BASES							NH_4 ABSORBED
	R_2O_3	Mn	Ca	Mg	Na	K	R_2O_3	Mn	Ca	Mg	Na	K	Total	
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*milliequivalents per kilo*							
Soil 1286														
0.05*N* HCl	1.54	T	0.600	0.220	0.033	0.078	...	..	300	181	14	20	.....	.....
N NH_4Cl	......	......	0.520	0.088	0.016	0.076	...	..	260	72	7	19	368	327
NH_4Cl*	......	......	0.434	0.073	0.028	0.053	...	..	220	64	12	13	304	273
N NaCl	......	......	0.470	0.078	.....	.....	...	..	235	64	...	..	.....	.....
N KCl	......	......	0.510	0.092	.....	.....	...	..	255	76	...	..	.....	.....
N $CaCl_2$	......	......	.....	.....	0.018	0.058	...	..	...		8	15	.....	.....
N $AlCl_3$	......	......	0.590	0.078	.....	.....	...	..	295	64	...	..	.....	.....
Soil 1293														
0.05*N* HCl	1.45	0.065	0.284	0.180	0.180	0.053	...	24	142	148	78	14	.....	.....
N NH_4Cl	......	0.060	0.308	0.128	0.031	0.044	...	22	154	105	14	11	306	322
N NaCl	......	......	0.303	0.127	.....	.....	...	..	152	104	...	..	.....	.....
N KCl	......	......	0.312	0.126	.....	.....	...	..	156	104	...	..	.....	.....
N $CaCl_2$	......	0.053	.....	0.182	0.047	0.034	...	19	...	150	20	9	.....	.....
Soil 1294														
0.05*N* HCl	......	0.132	0.475	0.114	0.028	0.039	...	48	237	93	12	10	.....	.....
N NH_4Cl	0.0700	0.111	0.520	Lost	0.033	0.059	32	40	260	(93)	14	15	454	457
N NH_4Cl†	......	......	.....	.....	.....	.....	...	..	218	....	...	..	374	....
N NaCl	0.0070	0.115	0.480	0.107	.....	.....	3	42	240	87	...	..	.....	.....
N KCl	0.0085	0.125	0.500	0.120	.....	.....	4	45	250	98	...	..	.....	.....
N $CaCl_2$	......	0.115	.....	0.250	.....	.....	...	42	...	203	...	..	.....	.....

Soil 1295														
0.05*N* HCl	1.620	0.0052	0.320	0.140	0.030	0.027	...	2	160	115	13	7	.....	.....
N NH_4Cl	0.225	0.0025	0.334	0.125	0.037	0.050	103	1	167	103	16	13	403	394
N NaCl	0.072	0.0017	0.335	0.126	.....	.....	33	1	162	104	...	..	.....	.....
N KCl	0.163	0.0022	0.305	0.123	.....	.....	74	1	153	101	...	..	.....	.....
N $CaCl_2$	0.360	......	.....	0.344	.....	.....	164	..	...	283	...	..	.....	.....
Soil 1296														
N NH_4Cl	......	T	0.37	0.865	0.55	0.132	...	..	185	710	240	34	1,169	1,070
N NaCl	......	......	0.44	0.760	.....	.....	...	..	220	625	...	..	.....	.....
N KCl	......	......	0.37	0.790	.....	.....	...	..	185	650	...	..	.....	.....
N $CaCl_2$	......	......	.....	1.120	.....	.....	...	..	...	920	...	..	.....	.....

Kelley (3).
Parker (5).

NaCl treatments. The alkalinity produced in soil 1294 is negligible and this is also true of soils 1293 and 1295, which gave titers almost identical with those recorded for soil 1294. The colloid 1296–Na yields a slight alkalinity

TABLE 6

Reaction of soils treated to exchange their replaceable base for a single base

SOIL	BASE	pH Air-dried soil	pH Oven-dried soil
Trenton clay (T-1)	Na	8.95	8.15
	K	8.65	7.85
	Ca	8.40	7.55
	NH_4	8.20	7.80
	U*	8.40	7.80
1170	Na	8.55	7.95
	K	8.10	7.33
	Ca	....	7.47
	NH_4	7.00	5.80
	U*	....	7.50
	H	....	4.85
1170-A	Na	....	8.08
	K	8.20	7.15
	Ca	....	7.50
	NH_4	6.77	6.00
	U*	8.90	7.55
	H	4.60	4.55
	Al	....	4.75
1171	Na	8.65	7.70
	K	8.95	7.57
	Ca	....	7.60
	NH_4	6.60	6.25
	U*	8.70	7.90
	H	....	5.55
1286	Na	....	7.70
	K	....	7.00
	Ca	....	6.95
	NH_4	....	5.70
	U*	....	6.70
	H	....	4.50
	Al	....	4.65

SOIL	BASE	pH Air-dried soil	pH Oven-dried soil
1293	Na	7.90	6.70
	K	7.70	6.15
	Ca	7.65	6.55
	NH_4	7.42	5.55
	U*	6.65	6.05
	H	3.85	4.65
1294	Na	7.25	6.20
	K	7.00	5.70
	Ca	6.60	5.75
	NH_4	6.70	5.65
	U*	6.00	5.25
	H	3.30	4.60
1295	Na	6.75	6.00
	K	6.80	5.80
	Ca	6.35	5.65
	NH_4	6.10	5.50
	U*	5.30	5.25
	H	3.65	4.60
1296	Na	7.70	....
	U*	7.60	....
	K	8.20	....
	Ca	8.00	....
	Mg	8.00	....
	NH_4	7.50	....

* Untreated natural soil.

as does also soil 1286–Na, and from the latter, enough organic matter was dissolved to make the filtrates dark colored.

The anaytical data for the replaced bases in the Utah soils (table 4) indicate

that the sum of the bases dissolved by NH_4Cl greatly exceeds the ammonium radical absorbed and retained by the solid after it has been washed and air-dried. On the other hand, the data for the other soils in table 5 show a close agreement between these quantities. The high pH values of the former group of soils as compared with the latter (table 6) seem to be associated with this difference of behavior.

TABLE 7

Complete chemical analyses of colloidal mineral 1296 in which the exchangeable bases have been replaced by a single base

BASE INTRODUCED	Mg	Ca	K	NH_4	Na	UN-TREATED
Per cent of oven-dried material						
SiO_2	62.00	61.90	59.10	62.10	61.10	62.10
Fe_2O_3	2.20	2.20	2.40	......	......	2.10
Al_2O_3	18.60	18.60	18.18	......	......	18.60
$Al_2O_3 + Fe_2O_3$	(20.80)	(20.80)	(20.58)	21.80	20.70	(20.70)
CaO	......	3.50	0.30	0.26	0.39	0.48
MgO	9.22	7.10	7.30	7.42	6.83	8.40
K_2O	0.38	0.31	5.20	......	0.40	0.30
Na_2O	0.30	0.30	0.38	......	3.28	1.33
$(NH_4)_2O$	......	......	......	2.60	......	......
H_2O (above 110°)	7.15	6.25	6.80	6.20	6.60	6.55
Total	99.85	100.16	99.66	100.38	99.30	99.86
Relative combining proportion						
SiO_2	100	100	100	100	100	100
Fe_2O_3	1.3	1.3	1.5	......	......	1.3
Al_2O_3	17.8	17.8	18.2	......	......	17.8
$Al_2O_3 + Fe_2O_3$	(19.1)	(19.1)	(19.7)	20.1	19.5	19.1
CaO	......	6.1	0.5	0.4	0.7	0.8
MgO	22.5	17.2	18.5	17.8	16.8	20.4
K_2O	0.4	0.3	5.6	......	0.4	0.3
Na_2O	0.5	0.5	0.6	......	5.3	2.1
$(NH_4)_2O$	......	......	......	5.0	......	......
H_2O	3.9	3.4	3.8	3.4	3.6	3.5
$CaO+MgO+K_2O+Na_2O+(NH_4)_2O$	23.4	24.1	25.2	23.2+	23.2	23.6

The reasons for the discrepancies in table 4 are to be sought in three directions: 1. Solubility of compounds other than carbonates without an equivalent absorption of base from the solution: if this solubility effect is continuous throughout the salt treatment it may prevent the complete replacement of the bases; 2. Hydrolysis of the exchange complex during the washing process; 3. Liberation of NH_3 when the soil is air-dried.

Kelley and Brown (4) observed that some alkali soils contain silicates that

are soluble in NH_4Cl, but they did not give data as to the quantity. In table 4 it will be seen that large amounts of silica are dissolved from the Ballard soils by NH_4Cl. The silica is probably combined with calcium and magnesium because NH_4Cl brings into solution considerably larger quantities of these bases than does either NaCl or KCl, the magnesium difference predominating. If correction is made for the bases combined with the silica on the assumption of a metasilicate, or if the lower Ca and Mg values are used in computing the sum of the replaceable bases, the agreement with the amount of NH_4 absorbed is better.

An explanation of the presence of soluble silicates in alkali soils follows from Bradfield's recent work on the reaction of bases with colloidal clay (2) in which it is shown that the clay absorbs much larger amounts of cations from an alkaline solution than from a neutral solution. This absorption probably takes place by breaking up the complex alumino-silicates into simpler molecules, some of which may be soluble in NH_4Cl. Since many alkali soils have experienced high OH-concentrations it is likely that some decomposition of the complex silicates into simpler salt-soluble forms has taken place.

The hydrolysis of Trenton clay has been discussed above. Nearly all the absorbed NH_4 had been lost from this soil before analysis. Part of this loss may have occurred when the sample was air-dried. It has been observed that the air-dry Utah soils loose about 30 per cent of the absorbed NH_4 on being heated at 110°, and even the soils in table 5 loose 10 per cent by this treatment, which is accompanied by a considerable decrease in pH (table 6).

When water is added to the sodium-saturated colloid 1296 a clear jelly is formed which is converted into a faintly opalescent fluid when the concentration of the solid is reduced to about 3 per cent. The other samples of 1296, with the exception of the untreated material, do not imbibe an appreciable amount of water but remain in a granular form. Their dispersions are milky. The untreated sample, which is partially sodium replaced, has properties intermediate between these extremes. The sodium-saturated soils 1293, 1294, and 1295 also assume a jelly form in water, and soil 1286 disperses readily. The water relations of a number of these soils as indicated by the moisture equivalent have already been published (6, table 5).

It will be shown in another paper[3] that the total amounts of bases replaced from this group of materials are closely correlated with their colloidal content and water absorption power, as suggested by Parker and Pate (5). The largest departures from this correlation occur in Trenton clay and soils 1170 and 1170–A. The high lime content of the former renders the determination of exchangeable bases inaccurate because the replacement probably does not go to completion. Soils 1170 and 1170–A show less difference in their base exchange capacities than their textures would indicate, and it is probable that some of the non-colloidal particles of soil 1170 participate in this process.

[3] Thomas, M. D. Aqueous vapor pressure of soils: IV. Influence of replaceable bases. Soon to appear in *Soil Science*.

In table 6 it will be seen that the pH of all the soil samples is reduced as a result of drying them at 110°, except in the case of the acid-treated materials, which show an increase in the reaction value to about pH 4.7. The change is usually less with the untreated soils. It is doubtless associated with a rearrangement of the acid groups in the silicate molecules, but the data are insufficient to elucidate the nature of the change.

In view of the fact that the colloid 1296 exhibits properties closely analagous to those of this series of soils, it is interesting to note the actual changes in the material brought about by the different salt treatments. Table 7 contains complete chemical analyses of the six different samples of No. 1296. These analyses indicate that the composition of this silicate is not exactly $(MgO) \cdot (Al_2O_3) \cdot (5SiO_2) \cdot (2H_2O)$ but rather $(6MgO) \cdot (5R_2O_3) \cdot (25SiO_2) \cdot (10H_2O)$. Neither the silica nor the alumina has been modified by the different salt treatments. Considering the wide range of properties shown by these materials it is perhaps surprising that they all contain 9 or 10 molecules of water removable above 110°. This indicates a marked difference from the behavior of the zeolite analcite in losing its combined water when it is converted into leucite. The colloidal mineral cannot be classed as a zeolite, however, since the latter contain no magnesium, but its empirical formula approximates Faujasite, except for the presence of Mg instead of Ca.

SUMMARY

1. Eight clays and a natural mineral colloid were treated to exchange their bases for a single base, and the process was followed by chemical analysis.

2. When alkali soils were leached with water there was a nearly constant solubility of the sodium on a high level of concentration as compared with the other bases, after the removal of soluble salts.

3. The alkali soils contained appreciable amounts of soluble silicates which were not present in the humid soils.

4. The arid soils showed a marked tendency to hydrolysis on washing out the soluble salt.

5. The discrepancies between the amounts of bases dissolved and NH_4 absorbed by the Utah soils were accounted for.

6. The arid soils had higher pH values than the other soils.

7. Drying at 110° changed the pH values considerably.

8. Chemical analyses of the colloid into which different bases had been introduced, showed that the material is a hydrated magnesium aluminum silicate in which about one-third of the Mg is replaceable by other bases. This material has properties closely analagous to those of the soils.

REFERENCES

(1) Bradfield, R. 1923 The chemical nature of a colloidal clay. Missouri Agr. Exp. Sta. Res. Bul. 60.

(2) Bradfield, R. 1927 The effect of hydrogen-ion concentration upon the absorption of calcium by a colloidal clay. *Soil Sci.* 24: 351–364.

(3) Kelley, W. P., and Brown, S. M. 1924 Replaceable bases in soils. Calif. Agr. Exp. Sta. Tech. Paper 15.

(4) Kelley, W. P., and Brown, S. M. 1925 Base exchange in relation to alkali soils. *Soil. Sci.* 20: 473–495.

(5) Parker, F. W., and Pate, W. W. 1926 Base exchange in soil colloids and the availability of exchangeable calcium in different soils. *Jour. Amer. Soc. Agron.* 18: 470–482.

(6) Thomas, M. D., and Harris, K. 1926 The moisture equivalent of soils. *Soil Sci.* 21: 411–424.

THE QUANTITATIVE DETERMINATION OF NITRITES IN SOIL[1]

R. P. BARTHOLOMEW

Arkansas Agricultural Experiment Station

Received for publication February 14, 1923

Attempts to extract nitrites quantitatively from flooded quartz cultures by the method recommended by Harper (2) for nitrates gave results lower than those indicated by a qualitative test made by the Griess red color method (5) for nitrites. Qualitative tests made with solutions of nitrite showed that when $CuSO_4$ was used in the solution, some nitrite was being converted to nitrate during the extraction. The amount transformed did not seem to be constant.

Water extracts even when Ca $(OH)_2$ is used as a flocculating agent are often turbid and cannot be used for colorimetric tests without being clarified. Lipman (3) obtained water extracts and then used aluminum cream to clarify them.

If some flocculating agent which did not affect the nitrites could be prepared in the extracting solution it would greatly simplify the procedure.

The purpose of this investigation was to find some method which would give a clear soil extract in a short time and yet have no effect on the nitrate content of the soil.

ALUMINUM SULFATE AS A FLOCCULATING AGENT

Aluminum being a trivalent metal should have a great flocculating power and $Ca(OH)_2$ could be added to precipitate the aluminum and hasten clarification.

Tests were made on the effect on nitrites of $Al_2(SO_4)_3 \cdot 18\ H_2O$ and $Ca(OH)_2$ alone and combined. The results (table 1) obtained by the Griess red color method show that neither has any effect upon the nitrites. An 8 per cent solution of aluminum sulfate was used arbitrarily for the tests made.

Additions of 1, 3, 5, 10, and 15 cc. of aluminum sulfate were made to 250 cc. of water for extraction of equal amounts of soil. The soil was shaken with the aluminum sulfate for 10 minutes. Then approximately 1 gm. of calcium hydroxide was added and shaken thoroughly once and left standing. The soil in all samples settled very quickly but the supernatant liquid was somewhat turbid in the 1-, 3-, and 5-cc. additions. The one receiving 10 cc. was only

[1] Published with the permission of the Director of the Arkansas Agricultural Experiment Station.

slightly cloudy and the one containing 15 cc. was very clear. The 15-cc. addition, or 1.2 gm. aluminum sulfate in 250 cc. of water, was adopted for use in the method.

SOLUBILITY OF DYE IN GRIESS RED COLOR METHOD

A 0.5 per cent solution of sulfanilic acid in 30 per cent acetic acid and a similar solution of alpha-naphthylamine were used as recommended by Briggs (1) for the Griess reaction. To develop the color, 2 cc. of the first and 1 cc. of the latter reagent were used.

In order to determine what concentrations would give the most desirable color for reading, a series of standards covering the ranges recommended by Treadwell and Hall (5) was prepared and the color developed. Attempts to read the colors in the stronger concentrations, from 0.2 to 0.4 p.p.m. nitrogen as nitrite, failed because of a reddish-brown precipitate which had developed. Further study revealed that 0.2 p.p.m. of nitrogen as nitrite was the greatest

TABLE 1

Stability of nitrites in solutions of aluminum sulfate and calcium hydroxide

SUBSTANCE AND AMOUNT USED PER 250 CC. WATER	NITROGEN AS NITRITE	
	Added	Found by analysis
	p.p.m. per cc.	*p.p.m. per cc.*
1 gm. $Ca(OH)_2$	0.05	0.05
1.2 gm $Al_2(SO_4)_3 \cdot 18\,H_2O$	0.05	0.05
1 gm. $Ca(OH)_2$; 1.2 gm. $Al_2(SO_4)_3 \cdot 18\,H_2O$	0.05	0.05
1 gm. $Ca(OH)_2$; 1.2 gm. $Al_2(SO_4)_3 \cdot 18\,H_2O$	0.10	0.10

concentration at which the color could be developed without producing a precipitate that would affect the color. In fact a precipitate will come out of a concentration of 0.2 p.p.m. if it stands for 3 hours. However, the color can be read before that time with accuracy.

The precipitate came out of solutions containing more than 0.2 p.p.m. nitrogen as nitrite even when the reagents prepared as recommended by Treadwell and Hall were used. The concentrations finally adopted were from 0.05 to 0.1 p.p.m. nitrogen as nitrite.

ACCURACY OF METHOD

In order to test the accuracy of the method, 50 p.p.m. nitrogen as nitrite were added in 5 cc. of water to 50 gm. of soil and the nitrites extracted as suggested above. When the red color of the Griess reaction was developed in an aliquot and compared with a standard it was found that 22 p.p.m. of nitrogen added as nitrite were no longer present in that form. At the end of 1 hour only a slight trace of nitrites could be extracted from the soil. Tests with other soils gave similar results.

From the results obtained it was evident that either the reagents used in the method or the soil itself was instrumental in converting the nitrites into some other form. Withers (6) reports similar results but gives no explanation of them. Tests to be discussed later showed that the soil was causing the transformation and that sterilization for 6 hours would prevent it in most soils.

Definite amounts of sodium nitrite were added in solution to several 50-gm. samples of soils which had been sterilized in an autoclave for 4 hours at 12 pounds pressure. The nitrites were extracted from the 50-gm. samples as given above with 250 cc. of water containing 1.2 gm. aluminum sulfate and the nitrites were determined by the Griess red color reaction. The results are given in table 2.

TABLE 2

Amounts of nitrites recovered from sterilized soil

STERILIZED SOIL	TIME ELAPSED BEFORE ALALYZED	NITROGEN AS NITRITE	
		Added	Found in extract
	hours	*p.p.m. per gram soil*	*p.p.m. per gram soil*
Silt loam	None	24.6	24.60
Silt loam	1	24.6	24.60
Silt loam	2	24.6	24.60
Silt loam	24	24.6	24.60
Sand	None	24.6	24.60
Sand	1	24.6	24.60
Sand	2	24.6	24.20
Sand	24	24.6	24.60
Silt loam	None	1.0	0.84
Silt loam	1	1.0	0.72
Sand	None	1.0	0.84
Sand	1	1.0	0.80

The results indicate that the method used extracted the nitrite from the soil. Even when such a small amount as 1 p.p.m. was added to the soil, most of the nitrogen was recovered as nitrite. The amount not recovered was probably oxidized to nitrate by the air. The extremely small amount not recovered could not be detected as nitrates because it is less than the experimental error of the phenoldisulfonic acid nitrate test.

The method has been used in this laboratory and has given excellent results even with suspensions of colloidal silica obtained from quartz cultures.

CONVERSION OF NITRITES TO NITRATES IN THE SOIL

While the development of the nitrite method mentioned above was being attempted, it was found that whenever nitrites were added to field soils, a large part of the nitrites could not be found in the extracts. In order to

determine whether the method was extracting all the nitrogen existing as nitrites in the soil it was necessary to determine what had caused the loss of the nitrite added.

Qualitative tests made by the phenoldisulfonic acid method showed an increase in nitrate content in the extract from the soil receiving the addition of nitrites.

A solution of sodium nitrite equivalent to 24.6 p.p.m. nitrogen as nitrite per gram of soil was added to 50 gm. of soil, and the soil extracted at different

TABLE 3

Nitrite converted to nitrate in silt loam soil

TREATMENT	TIME ELAPSED BEFORE EXTRACTION	NITROGEN AS INDICATED PER GRAM OF SOIL			
		NO_2	NO_2 changed to some other form	NO_3	Increase in NO_3
	hours	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Check	None	0	0	56.0	0
N as NO_2 added	0	18.7	6	66.6	10.6
N as NO_2 added	1	17.7	7	69.0	13.0
N as NO_2 added	2	11.8	13	70.0	14.0

TABLE 4

Amounts of nitrite converted to nitrates in unsterilized soils

UNSTERILIZED SOILS	NO NITRITES ADDED		NITRITES ADDED							
			Extracted at once		Extracted after 1 hour		Extracted after 2½ hours		Extracted after 6 hours	
	N as NO_2	N as NO_3	N as NO_2	N as NO_3	N as NO_2	N as NO_3	N as NO_2	N as NO_3	N as NO_2	N as NO_3
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Clay loam	Slight trace	6.5	8.5	*	7.2	8.3	6.8	13.3	3.22	14.3
Silt loam	Slight trace	2.5	5.5	4.35	5.1	11.1	3.8	16.0	2.1	20.0
Sand	Slight	1.8	8.9	*	7.6	5.5	7.0	8.0	7.2	6.9

*Not determined.

intervals. The extract was analyzed for nitrates and nitrites. The nitrates were determined by the phenoldisulfonic method in aliquots from the aluminum sulfate extraction. It was necessary to filter the solution after developing the yellow color in order to remove a residue which came out on evaporation. The results are given in table 3.

From the results it would seem that all nitrites not recovered as such were converted to nitrates. The conversion took place very rapidly as 6 parts per million of nitrogen as nitrite was converted to nitrate as soon as it was added to the soil.

A similar experiment was made on clay loam, silt loam, and sand soils which had not been sterilized. To each gram of soil 9½ p.p.m. of nitrogen as nitrite was added and the extractions were made at the intervals given. The results are given in table 4.

The results agree with those of the preceding experiment in that there is a reduction in the amounts of nitrite with a corresponding increase in the amounts of nitrates in the soil.

There are two possibilities as to the manner in which the nitrite is being converted to the nitrate: one, that it is due largely to biological activities; and the other, that it is due to a chemical oxidation.

The results previously given for the recovery of nitrates from sterilized soil indicated that there is very little chemical oxidation taking place.

The results given for unsterilized soils show that a large amount of the nitrite has been converted to nitrates. This conversion in all probability has been due to biological activities. This is substantiated by results reported by Withers (6) who could detect no increase in nitrites in sterile soil 4 weeks after the addition of nitrites.

The rapidity of change does not take place in a definite order as suggested by Miyake (4) unless a separate formula is set up for each soil. In the case of sand, there was a gradual decrease in the nitrite content. In the case of the silt loam, there was a rapid, then a gradual and then another rapid decrease in the nitrite content. The clay loam is the only one that apparently follows, at least for the time studied, Miyake's suggestion that the transformation is first slow, then rapid, and then slow again. This is what might be expected because of the difference in numbers of bacteria and amount of organic matter which would be present in the different soils.

SUMMARY

A study was made of the value of aluminum sulfate and calcium hydroxide as a clarifying agent in the extraction of nitrite nitrogen from soils. Some observations were made of the rate of the transformation of nitrite to nitrate. The results may be summarized as follows:

1. Aluminum sulfate and calcium hydroxide used in the solution for the extraction of nitrites from soil gave a clear extract in a short time.
2. All the nitrogen present in soils as nitrite was extracted by this method.
3. Nitrites are converted to nitrates very rapidly in soil. The transformation is largely due to biological reactions.

REFERENCES

(1) Briggs, A. P. 1923 A study of the inorganic elements of blood plasma. *Jour. Biol. Chem.* 57: 351.

(2) Harper, H. J. 1924 The accurate determination of nitrates in soils,—Phenoldisulphonic acid method. *Jour. Indus. Engin. Chem.* 16: 180–183.

(3) Lipman, J. G. 1902 Studies in nitrification. *Jour. Amer. Chem. Soc.* 24: 171–186.

(4) MIYAKE, K. 1916 On the nature of ammonification and nitrification. *Soil Sci.* 2: 481–492.
(5) TREADWELL, E. P., AND HALL, W. T. 1919 Analytical Chemistry, vol. 2, p. 346. New York.
(6) WITHERS, W. A. 1906 Studies of changes which take place in nitrogen where added to soils in different forms of combination. *N. C. Agr. Exp. Sta. Ann. Rpt.* 1906: 15–18.

THE RELATION OF THE CONCENTRATION OF CALCIUM ION REQUIRED BY ALFALFA TO THE AMOUNT PRESENT IN SOIL SOLUTION[1]

HAROLD W. E. LARSON[2]

Oregon Agricultural Experiment Station

Received for publication February 18, 1928

Virgin soils of humid regions are known to contain larger amounts of calcium than soils that have been cropped for several decades. Through cropping and leaching with acids, such as carbonic and sulfuric, much calcium is removed, allowing hydrogen ions to replace the exchangeable calcium of the ultra-clay complex, thus causing the formation of a soil unsaturated with bases (5). Lysimeter studies at Oregon Agricultural College have shown that 32 to 234 pounds of calcium per acre is lost annually by leaching (7).

Plants vary in their calcium requirement, the legumes requiring much larger amounts than non-legumes. Although some legumes, such as soybeans, dalea, and vetch, can thrive in soils which are decidedly acid in reaction, they require a relatively high concentration of soluble calcium to make their best growth. Alfalfa and sweet clover are less tolerant of acidity and require a soil which contains a relatively large amount of readily available calcium.

Very little work has been done heretofore for the purpose of determining a suitable concentration of calcium for plant nutrition. Some studies have been carried on in the past at the Oregon station, the results of which indicated that alfalfa requires a higher concentration of calcium and nitrogen than of other essential nutrients in order to live and make satisfactory growth.

The object of the present investigation is to learn the effect of maintaining different calcium concentrations upon the growth of alfalfa, and also to learn the seasonal variation in water-soluble calcium in field soils and in treated soils in jars. The change in replaceable calcium content and in reaction of soils due to treatment is also reported.

PLAN OF STUDY

Water culture solutions were employed for studying the minimum concentration of calcium required by alfalfa to make satisfactory growth. Two trials

[1] Contribution from Oregon Agricultural Experiment Station, released with the approval of the Director. Abstract of Master's Thesis.

[2] The writer takes this opportunity to thank Dr. W. L. Powers and Dr. R. E. Stephenson of the soils department of the Oregon Agricultural College for the many helpful suggestions and courtesies extended to him while he was conducting the studies reported in this manuscript.

were conducted, one in the spring and one in the winter. Nine different concentrations of calcium were used. Average day length was approximated by electric light, a 1000-candle power nitrogen bulb being used during the winter trial. The nutrient solution to which different concentrations of calcium were added was a modification of a solution used by Powers (10) and consisting of reduced concentration of the various nutrients, particularly magnesium, since small concentrations of calcium were employed in some of the series. Each series consisted of six 2-quart jars holding 3 plants each. The culture solutions were frequently renewed to maintain the desired concentrations and the hydrogen-ion concentration was maintained at pH 5.8 to 6.0 throughout the growing period. Calcium was supplied in the form of calcium sulfate.

The seasonal variation of water-soluble calcium in soils was studied under controlled conditions in 4-gallon earthenware jars and also under field conditions. The Melbourne silty clay loam and Willamette silty clay loam were fallowed. A second series of each soil was prepared for the purpose of growing alfalfa. The soils used under field conditions were fallow and cropped Dayton silty clay loam and Chehalis fine sandy loam. The volumetric method for determining water-soluble calcium was used.

The study of the amount of exchangeable calcium was conducted with the same soils as those used in the study of the water-soluble calcium. The amount of calcium present in exchangeable form in all the soils but those treated with ground limestone, was obtained by first leaching with twentieth-normal hydrochloric acid and determining the calcium volumetrically. The limestone-treated soils were leached with tenth-normal barium chloride and the calcium was determined by the soap titration method as outlined by Breazeale (3).

The hydrogen-ion concentration of the soils at the beginning and at the close of the experimental period was determined electrometrically by the use of the hydrogen electrode.

EXPERIMENTAL

Experiment 1—study of calcium concentration

First trial. This trial was carried on for the purpose of studying the calcium requirement of the alfalfa plant. Accordingly, nutrient solutions containing varying amounts of calcium in the form of calcium sulfate were prepared in series of six 2-quart jars. Three seedlings having 2 to 3 leaves were transplanted to each of these jars from sand cultures. The trial was carried on in the greenhouse and lasted from December 1, 1926 to January 12, 1927. The amount of dry matter produced in the plant tops is shown in table 1.

In this trial, the effect of different concentrations did not become apparent until during the second week of the experiment. The plants growing in solutions containing no calcium and 2 p.p.m. respectively, died during the third week. These plants did not make any leaf growth but a slight increase in

length of roots took place. Plants growing in nutrient solutions containing 4 and 8 p.p.m. died before the end of the trial. The amount of top and root growth was proportional to the calcium concentration of the solution up to and including 32 p.p.m., indicating that the calcium requirement of the plant had been satisfied. The increased growth of the plants receiving larger amounts of calcium than 32 p.p.m. (fig. 1) tended to show that higher concentrations, although not toxic to the plant, are not necessary in water cultures. The minimum concentration required for plants to live, seems to be between 8 and 16 p.p.m. The roots of the plants grown in solutions having lower calcium concentrations were spindling, lacked nodules, and became more bushy as the concentration of calcium increased.

Second trial. A second trial similar to the first was conducted from May 18 to June 28, 1927. Differences in growth due to concentration of calcium did not become apparent until the latter part of the second week. The lack of

TABLE 1

Calcium concentration and growth of alfalfa

SERIES	CALCIUM	YIELD OF TOPS
	p.p.m.	*mgm.*
1	240	297
2	0	64
3	2	70
4	4	82
5	8	160
6	16	180
7	32	221
8	64	214
9	128	250
10	320	273

calcium in series 2 caused the leaves of the plants to have a reddish tinge which spread to the midrib. This effect of the lack of calcium was also noticed to some extent in the solutions containing 4 and 8 p.p.m. The only growth noticed in the no-calcium series was a slight increase in root growth. Plants receiving 4 p.p.m. of calcium, continued until death to send forth leaves which died within a few days, showing that perhaps the limited amount of calcium supplied, was being reused. Growth increased quite rapidly with the increase in concentration up to 128 p.p.m. Results obtained in this trial are presented in table 2.

The growth produced by the solution containing 32 p.p.m. seemed to be much more economically produced and was equal in quality to that produced by the higher concentrations. Plants receiving 8 p.p.m. of calcium were able to live throughout the period during this trial, as compared with those requiring 16 p.p.m. in the first trial, probably because of the greater amount of sunshine

received during the summer trial. Although the plants receiving 8 p.p.m. lived throughout the period and made growth, they and the plants receiving less calcium, did not develop normal sized leaves. Roots of plants receiving 8 or more p.p.m. of calcium were stocky and had many nodules; these characteristics being more pronounced as the concentration increased.

Experiment 2—calcium in the soil solution and amount of replaceable calcium

Studies of calcium concentrations in soil pots using Melbourne silty clay loam and Willamette silty clay loam were started March 28, 1927. Samples were taken from the fallow jars periodically and water-soluble calcium was determined. The replaceable calcium was determined on these samples at the beginning and at the close of the experimental period. Results are presented in table 3.

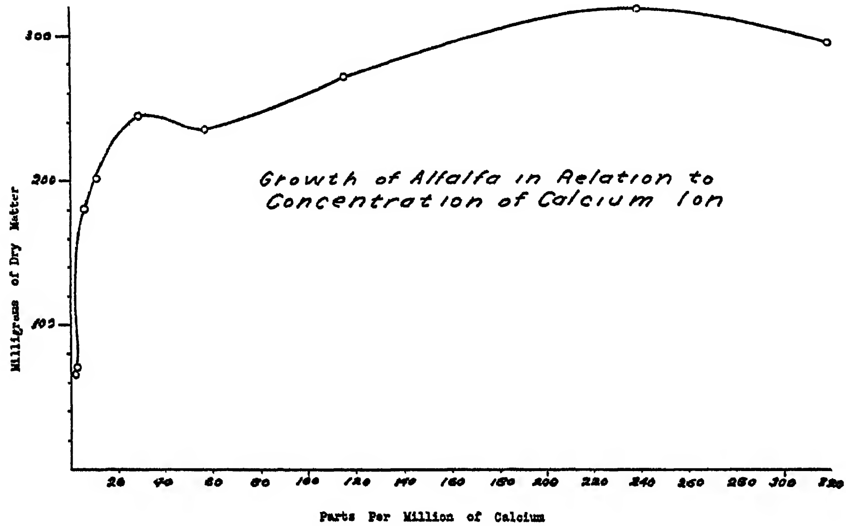


FIG. 1

All the treatments on Melbourne silty clay loam except limestone had a depressing effect upon the water-soluble calcium content of the soil during the first 6 weeks. The calcium content had begun to increase again at the end of 12 weeks and continued to do so during the remainder of the experimental period. However, it did not exceed the amount originally present. The amount of water-soluble calcium increased rapidly until the maximum was reached at the end of 12 weeks in the limestone-treated soil. The largest amount of water-soluble calcium was present in the limestone-treated soil at the end of the experiment. The sulfur-treated soil contained the second largest amount, followed in turn by that treated with manure and superphosphate. The largest amount of replaceable calcium was present in the limestone-treated Melbourne soil at the close of the experiment, followed

respectively by superphosphate, manure, and sulfur. The amount present in the sulfur-treated soil was smaller than that present in the check.

The effect of treatment on the water-soluble calcium content of Willamette silty clay loam was similar. The application of manure and superphosphate caused the water-soluble calcium content to be less than that of the check during the latter half of the experimental period. The application of sulfur to this soil caused the amount of water-soluble calcium to increase rapidly after the first 6 weeks. The amount of calcium present at the close of the experiment was larger where sulfur had been applied, than where limestone had been applied. This is in contradistinction to the results obtained with the Melbourne silty clay loam soil. Where limestone was applied, the amount of

TABLE 2

Calcium concentration and growth of alfalfa

SERIES	CALCIUM	YIELD OF TOPS	YIELD OF ROOTS	RATIO OF TOPS TO ROOTS
	p.p m.	*mgm.*	*mgm.*	
1	240	620	220	1:33
2	0	310	70	1:23
3	(Discontinued)			
4	4	350	103	1:29
5	8	435	109	1:25
6	16	645	211	1:33
7	32	630	273	1:43
8	64	500	192	1:38
9	128	1,265	546	1:43
10	320	995	371	1:37

TABLE 3

Soluble and replaceable calcium in certain fallow soils in pots

SOIL	TREATMENT PER ACRE	WATER-SOLUBLE CALCIUM					REPLACEABLE CALCIUM	
		March 28	May 7	June 18	July 30	September 10	March 28	September 10
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Melbourne	Check	57	31	39	37	37	2,653	2,915
	10 tons manure	57	37	42	50	49	2,653	3,023
	250 pounds sulfur	57	41	59	72	71	2,653	2,881
	450 pounds superphosphate	57	33	39	43	46	2,653	3,286
	4 tons ground limestone	57	91	99	98	89	2,653	4,015
Williamette	Check	42	22	33	47	60	2,668	2,768
	10 tons manure	42	26	32	29	59	2,668	3,121
	250 pounds sulfur	42	41	73	79	108	2,668	2,748
	450 pounds superphosphate	42	29	29	38	58	2,668	2,966
	4 tons ground limestone	42	96	76	72	93	2,668	3,206

water-soluble calcium reached its maximum during the first 6 weeks. It did not maintain this maximum but decreased during the next 12 weeks and then increased slightly to a point somewhat below its maximum.

Willamette silty clay loam soil treated with ground limestone contained the largest amount of replaceable calcium at the close of the experiment, followed respectively by the manure, superphosphate, and sulfur-treated soils.

Two cuttings of alfalfa were obtained from the cropped series of jars. The hydrogen-ion concentration of the fallow soils was determined at the beginning

TABLE 4

Yields of alfalfa obtained and hydrogen-ion concentration of soils

SOIL	TREATMENT PER ACRE	FIRST CUTTING	SECOND CUTTING	TOTAL YIELD	REACTION	
					March 28	September 10
		gm.	gm.	gm.	pH	pH
Potted soil:						
Melbourne silty clay loam	Check	2.4	3.0	5.4	6.32	6.16
	20,000 pounds manure	2.9	2.5	5.4	6.32	6.06
	250 pounds sulfur	1.7	2.3	4.0	6.32	6.03
	450 pounds superphosphate	3.7	3.1	6.8	6.32	6.15
	8,000 pounds ground limestone	3.0	3.4	6.4	6.32	7.77
Willamette silty clay loam	Check	3.5	1.4	4.6	6.57	5.78
	20,000 pounds manure	5.0	1.6	6.6	6.57	5.78
	250 pounds sulfur	4.0	1.9	5.9	6.57	5.44
	450 pounds superphosphate	3.5	1.8	5.3	6.57	5.64
	8,000 pounds ground limestone	5.1	1.5	6.6	6.57	7.26
Field soils:						
Dayton silty clay loam	Fallow	None	None	None	5.47	5.44
	Cropped	None	None	None	5.47	5.46
Chehalis fine sandy loam	Fallow	None	None	None	6.23	5.64
	Cropped	None	None	None	6.23	5.56

and at the close of the experimental period. The yields of alfalfa and the pH of the differently treated soils are shown in table 4.

The yield of alfalfa was increased by the application of ground limestone which maintained a high concentration of calcium in the soil solution throughout the period. However, the highest yield obtained on Melbourne soil was where superphosphate had been applied. This might be expected since Melbourne silty clay loam is rather low in phosphorus content (12). On the Willamette soil, manure benefited the growth measurably. The application of sulfur benefited the growth of alfalfa on the Willamette soil and depressed the growth on the Melbourne soil.

The application of ground limestone caused an expected decrease in

hydrogen-ion concentration, whereas the production of highly and slightly ionized acids by the application of sulfur and manure caused an increase. The hydrogen-ion concentration may be increased because of seasonal conditions during the spring and summer months (1, 8). This increase may be due to the dehydration of the hydrated colloidal silicate with a decrease in buffer action during the hot and dry summer months (1), or it may be due to the accumulation of salts in the soil during the summer, which tend toward increased acidity. (4)

Experiment 3—amount of calcium in field soils

The effect of season and crop under field conditions upon the calcium content of soils was studied on Dayton silty clay loam and Chehalis fine sandy loam. Analysis for water-soluble calcium was made at 6-week intervals. The amount of replaceable calcium present was determined at the beginning and at the end of the experimental period. This experiment was started March 28, 1927 and terminated September 10, 1927. Results are presented in table 5.

TABLE 5

Soluble and replaceable calcium in certain field soils

SOIL	TREATMENT	WATER-SOLUBLE CALCIUM					REPLACEABLE CALCIUM	
		March 28	May 7	June 18	July 29	September 10	March 28	September 10
		p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
Dayton silty clay loam	Fallow	57	15	18	14	19	2,000	2,081
	Cropped	27	13	7	14	20	1,813	1,948
Chehalis fine sandy loam	Fallow	34	20	24	27	35	2,886	3,157
	Cropped	50	18	22	24	37	3,360	3,551

The water-soluble calcium content of these soils was low during the spring and early summer, but during the late summer and early fall, the content began to increase, giving evidence of a season of low and a season of higher water-soluble calcium content during the year. The fallow soils contained somewhat more water-soluble calcium than the cropped soils, during the entire period except at the time of taking the last sample. The Chehalis soil contained more water-soluble calcium than the Dayton soil.

DISCUSSION

The concentration of soluble calcium favorable for normal plant growth seems to be about 32 to 64 p.p.m. This confirms the results of a previous trial made by Hartman and Powers (7). The plants were not injured by the higher concentrations employed, which would indicate that the calcium is not toxic

when present in excess. From 16 to 32 p.p.m. seems to be the minimum and 32 p.p.m., the most economical concentration. With higher concentrations, increased yields were obtained in accordance with the law of diminishing returns.

The concentration of calcium in some acid soils such as Dayton silty clay loam, Chehalis fine sandy loam, Willamette silty clay loam, and Melbourne silty clay loam at certain seasons seems to be unfavorably low for normal growth of alfalfa. Stewart (11) found that the soil solution of some of the irrigated soils of California contained less calcium than that which seems to be the economic requirement of alfalfa in these experiments. The plant requires the largest amount of calcium during its early growth (2) and it is important that the calcium content be maintained throughout the season (6).

If normal growth is to be maintained on certain soils, the application of limestone must be made at regular intervals. It is also possible to believe that a higher concentration of calcium is necessary in the soil solution than is required in a culture solution, since calcium performs many other functions in the soil, such as improvement of tilth, correction of acidity, aiding of biological activity, and aiding of the absorption of anions and neutralizing toxins. Furthermore, diffusion is probably slower in soils than in culture solutions.

The results reported here (table 3) tend to show that the production of acids in some soils seems to increase the water-soluble calcium in proportion to the degree of ionization of the acid. The slightly ionized organic acids produced by the decomposition of manure did not bring as much calcium into solution as the highly ionized sulfuric acid in the two treated soil series.

Since many soils contain barely sufficient concentrations of calcium to supply the crop growing on them, and since some of that amount must be used for purposes other than nutrition, it is reasonable to believe that in order to obtain maximum yields of crops such as alfalfa and red clover, the application of lime is necessary from a nutritional standpoint as well as from the standpoint of the correction of soil acidity, of improvement of physical condition of the soil, and of biological activity. The amount of replaceable calcium present in the soil may represent a source of the water-soluble calcium since it can be brought into solution by base exchange and by the action of acids formed within the soil. Analyses given in table 3 show that the amount of calcium that disappeared from the replaceable form in the Melbourne soil is practically equivalent to the increase in calcium in the soil solution due to the treatment with sulfur. The lack of such relationship in the sulfur-treated Willamette soil would indicate that a solubility effect had been experienced.

The results obtained in this study should be valued conservatively since the period of time employed was rather short; also, in the study of the nutritional requirements no means of taking into account the amount of calcium present in the seed was employed. A continuance of the study of calcium concentration in the soil over a much longer period of time would yield results of greater value to a student of soil fertility.

CONCLUSION

1. The following relationships were found between the alfalfa plant and calcium-ion concentration.

A. The minimum concentration of calcium ion required by the alfalfa plant to make growth appears to be about 16 p.p.m. The most economical growth was produced with about 32 p.p.m.

B. Calcium present in excessive concentrations does not seem to be toxic to the plant, instead, increased growth may be produced.

C. The presence of sufficient calcium ion in a solution produces a strong, healthy plant with a stocky root system which when inoculated has a large number of nodules.

2. The studies of the effect of season and treatment on water-soluble calcium content in soils, in field, and in pots yield the following conclusions:

A. The water-soluble calcium content of certain soils is found to be below the amount necessary for a satisfactory growth of alfalfa in solution culture.

B. The application of ground limestone and sulfur increases the water-soluble calcium content of the soils as used in this investigation.

C. By the application of ground limestone, the water-soluble content of some soils can be increased and maintained throughout the season at a concentration which will eliminate calcium as the limiting factor in plant growth.

D. The soluble calcium content of some soils seems to be lowest during the early part of the season, which is the time that the plant requires calcium in large amounts.

3. The amount of replaceable calcium present on the ultra-clay complex varies during the season; also, the application of limestone tends to increase the amount present. It is probable that calcium tends to conserve the base-absorbing capacity of the soil or prevent soil deterioration.

4. It is probable that the application of ground limestone to many soils would prove of benefit from a nutritional standpoint as well as from its physical, chemical, and biological effects.

REFERENCES

(1) Baver, L. D. 1927 Factors affecting the hydrogen-ion concentration of soils. *Soil Sci.* 23: 399–414.

(2) Burd, J. S. 1919 Rate of absorption of soil constituents at successive stages of plant growth. *Jour. Agr. Res.* 18: 51.

(3) Burgess, P. S., and Breazeale, J. F. 1926 Methods for determining the replaceable bases of soils, either in the presence or absence of alkali salts. *Univ. Ariz. Tech. Bul.* 9: 198.

(4) Crowther, E. M. 1925 The soil reaction of continuously manured plots at Rothamsted and Woburn. *Jour. Agr. Sci.* (*England*) 15: 222.

(5) Gedroiz, K. K. 1915 The action of electrolytes on clay suspension. Bur. Agr. and Soil Sci. of the Sci. Comm. Main Dept. Land Organ. and Agr. Commun. 24. Trans. by S. A. Waksman.

(6) Gericke, W. F. 1925 Salt requirements of wheat at different growth phases. *Bot. Gaz.* 80: 410.

(7) Hartmann, Jr., Chas., and Powers, W. L. 1928 The crop-producing power of limiting quantities of essential plant nutrients. *Soil Sci.* 25: 371–377.

(8) Kelley, A. P. 1923 Soil acidity, an ecological factor. *Soil Sci.* 16: 41–54.
(9) Loew, O. 1899. Physiological rôle of mineral nutrients. *U. S. Dept. Agr. Div. Physiol. Path. Bul.* 18: 1.
(10) Powers, W. L. 1927 Studies with sulfur in relation to the soil solution. *Univ Calif. Pubs., Agr. Sci.* 5: 119–166.
(11) Stewart, G. R. 1918 Effect of season and crop growth in modifying the soil extract. *Jour. Agr. Res.* 12: 311.
(12) True, R. H. 1922 The significance of calcium for higher green plants. *Science* 55: 1.

AQUEOUS VAPOR PRESSURE OF SOILS: III. SOIL STRUCTURE AS INFLUENCED BY MECHANICAL TREATMENTS AND SOLUBLE SALTS

MOYER D. THOMAS[1]

Utah Agricultural Experiment Station

Received for publication January 30, 1928

It has been shown in an earlier paper (5) that the vapor pressure-moisture relation of a soil is modified by preliminary treatments such as wetting and drying and it seems evident that a study of this function should yield important data concerning the physical condition of the soil sample as influenced by other mechanical and chemical treatments. It is well known that an agricultural clay must not be handled when it contains enough moisture to render it plastic, and further that freezing and thawing improve the physical condition of a clay which has been mechanically puddled. It is also well known that saline soils usually have very good physical structure due presumably to a flocculating action of the salt on the soil colloids. In this paper these three factors are studied through the vapor pressure-moisture relations. The work is practically all confined to a consideration of Trenton clay, which has already been described (5).

EXPERIMENTAL

Samples of the soil which had been thoroughly washed to remove soluble material were placed in small aluminum cans provided with tightly-fitting covers and were brought to a moisture content of 30 per cent, the wetting being accomplished by the addition of water or of salt solutions containing different amounts of the chlorides of sodium, potassium, calcium, magnesium, and aluminum; the sulfates of sodium, iron, and aluminum; and finally sodium carbonate. Duplicate treatments were prepared. One series was frozen at -18°C. to -22°C., then melted and refrozen, the process being repeated five times. The other series was worked with a spatula to simulate a very thorough puddling. These materials were then subjected to the static vapor pressure process, by placing them in vacuum desiccators containing sulfuric acid or potassium chloride solutions of known concentration, and allowing the soil to

[1] Chief Chemist, Department of Agricultural Research, American Smelting & Refining Company, Salt Lake City, Utah. Formerly Associate Soil Chemist, Utah Agricultural Experiment Station.

The author acknowledges assistance with the experimental work of this series of papers from Karl Harris and J. N. Abersold. He inadvertently omitted a similar acknowledgement due to A. C. Sessions in an earlier paper (5).

come to moisture equilibrium with the solution through the vapor phase. Each desiccator accommodated 12 to 18 cans, which included all the samples that had been treated with a particular salt. Vapor pressure determinations were made first by drying the soils progressively over acid of increasing concentration, then drying at 110°, and subsequently wetting the samples by successive stages over acid of decreasing concentration. With heavy soils like Trenton clay, moisture equilibrium is obtained very slowly, 1 to 3 months

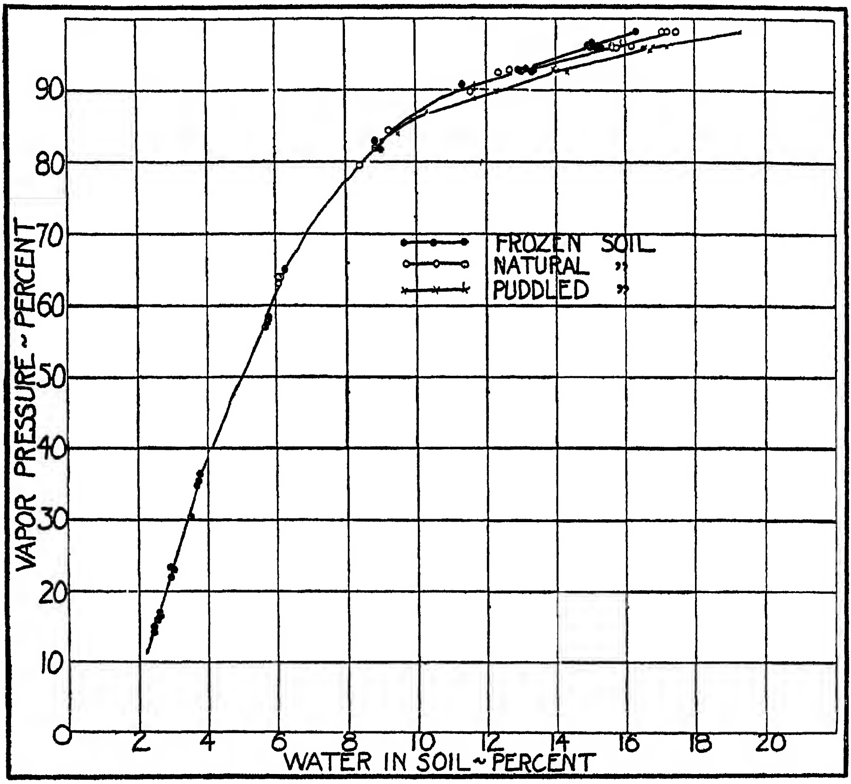


Fig. 1. Vapor Pressure-Moisture Diagram of Trenton Clay Showing the Influence of Mechanical Treatments on the Function

being required at each stage, particularly at high vapor pressures. However, the process demands only periodic attention at intervals of 2 or 3 weeks and it is possible for two men to make about 200 weighings and the necessary analyses and changes of the acid in one day. It is essential to keep the desiccators in the dark and at an approximately constant temperature.

The data for Trenton clay, to which no salt was added, are plotted in figure 1. Since in each group of samples which received a given salt treatment, check samples were included to which no salt was added, the data in figure 1 represent

a large number of determinations which approximately replicate each other and thus indicate the degree of precision which may be obtained by this vapor pressure technique. Evidently the method is entirely satisfactory, except at high vapor pressures, where the discrepancies are probably due in part to slight disturbances of the vapor equilibrium in the desiccator as a result of small temperature gradients and in part to slight differences in the physical condition of the different replicate samples.

INFLUENCE OF PHYSICAL TREATMENTS

It will be seen from figure 1 that freezing reduces and puddling increases the absorptive power of the soil for water at vapor pressures above 85 to 90 per cent. These physical treatments have no influence on the curves at lower vapor pressures. The values for the ratios of the moisture held by the puddled and frozen samples (P/F) at the same vapor pressure are given in table 1, in

TABLE 1

Ratios of moisture contents of puddled and frozen soil samples at the same vapor pressure

SOIL	RATIO P/F ON DRYING CURVES AT VAPOR PRESSURES						RATIO P/F ON WETTING CURVES AT VAPOR PRESSURES			
	98 per cent	95 per cent	92 per cent	87 per cent	83 per cent	57 per cent	98 per cent	94 per cent	92 per cent	81 per cent
Trenton	1.14	1.15	1.10		1.02	1.00	1.08		1.030	1.00
1170		1.16		1.035		1.00	1.05	1.015		1.00
1170-A		1.09		1.115		1.00	1.01	1.040		1.01
1171		1.11	1.08		1.035	1.00	1.02		1.025	1.00
1286		1.14		1.075		1.02	1.06	1.020		

which are also included some data of similar treatments with other soils. It is clear from table 1 that the process of oven drying does not change the relation between the frozen and puddled samples at high moisture contents, except to make the difference in water absorption power smaller.

Since at high vapor pressures we are dealing with water in the larger capillaries of the soil mass we may reasonably conclude that these physical treatments affect only the larger capillary spaces of the soil. In order to obtain some idea as to the magnitude of these spaces which are influenced we may employ the thermodynamic relation

$$M\,2t$$

$$RT\,ln\,\frac{P_0}{P_1}$$

in which r represents the radius of a capillary tube in which the vapor pressure of water is reduced to the value P_1 from the value P_0 of a flat water surface and t is the surface tension of water. The other symbols have their usual significance. From this equation the values of r corresponding to different values of P_1 are tabulated in table 2.

It is thus evident that the physical effects described above are confined to capillaries of larger radius than about 5 to 10 millimicrons. Mechanical analysis data and also values found by other methods (1, 4) indicate that the colloidal material of soil has an average radius of 40 to 60 millimicrons. The size indicated above for the radius of the smallest capillaries which are affected by the mechanical treatments described is, therefore, of the same order of magnitude as that of the colloidal soil particles. This circumstance gives a considerable degree of plausibility to the results derived from the use of the thermodynamic equation. It may be pointed out that the equation is also inherently reasonable because of the fact that the calculated vapor pressures approach zero at values of the radius corresponding to molecular dimensions.

TABLE 2

Relation between P_1 and r from the equation $r = \dfrac{M\,2t}{RT \ln \dfrac{P_0}{P_1}}$

VAPOR PRESSURE (P_1) PER CENT OF P_0 (25°)	RADIUS (MILLIMICRONS)
99.9	1085.00
99.0	109.00
98.0	54.50
96.0	26.30
95.0	21.20
90.0	10.30
85.0	6.65
80.0	4.85
50.0	1.56
30.0	0.91
10.0	0.47
3.0	0.31
1.0	0.23

A physical picture of the changes produced by puddling a clay involves a general reduction of the size of the capillary spaces larger than 5 to 10 millimicrons radius. The following calculation shows the nature of these changes. If at 95 per cent vapor pressure the puddled soil absorbs 15 per cent more water than the frozen soil, and 70 per cent more than at 85 per cent vapor pressure, and if we assume that the capillary spaces smaller than 5 millimicrons radius are the same in both cases, it follows that the puddled sample has about 30 per cent more capillary capacity in the size range between 5 and 26 millimicrons than the frozen material.

The difference between the moisture percentages of Trenton clay due to these physical treatments is the same at 98 per cent vapor pressure as at 96 per cent—that is, the capillary capacity in the size range between 26 and 55 millimicrons is identical in both treatments. The vapor pressure study does not extend to sufficiently moist soils to give a complete representation of the changes caused

by these manipulations, but it is likely that in the frozen soil the capillary spaces larger than a certain size have greater volume than the spaces of similar dimensions in the puddled soil. Table 1 seems to indicate that this limiting size is approached at 55 millimicrons. It is not desired to lay great emphasis on the dimensions quoted above, but rather to suggest the order of magnitude of the effects noted.

INFLUENCE OF SOLUBLE SALTS

When soluble salt is added to a soil two results are to be expected: First, the increased concentration of the soil solution will cause a lowering of its vapor pressure, which will be manifested by an increase in the amount of water absorbed by the soil at a given vapor pressure; and second, the salt may change the soil structure, which will increase or decrease the water-absorbing power, depending on the nature and concentration of the salt.

The data for the chloride treatments of Trenton clay are presented graphically in figure 2, the amount of water absorbed at a given vapor pressure being plotted at the ordinate against the salt concentration as the abscissa. The theoretical changes in moisture absorption due to salt treatment based on the assumption that the salt is all present in the soil solution and exerts its effect independently of the soil, are also indicated. The values for the higher salt concentrations are analyzed in table 3, the observed and calculated values of the moisture contents and vapor pressure lowerings being set down side by side. The calculation for sodium chloride and potassium chloride is based on recent experimental vapor pressure data (2) for these salts and is evidently reliable. The calculated values for calcium and magnesium chlorides, however, are based on a few freezing point determinations at about normal concentration and there is some uncertainty in regard to the accuracy of the calculations.

The aluminum salt is assumed to have been converted entirely into the calcium and magnesium salts by interaction with the lime present in the soil. This assumption is supported by the fact that when the aluminum-treated soil is leached with water, no aluminum is obtained in the filtrate but rather calcium and magnesium salts. It was determined by independent measurements that the addition of iron and aluminum hydroxides increased slightly the water-absorbing power of the soil and the observed values of the moisture absorption have been corrected by these amounts before they have been compared with the calculated values.

The data indicate that except in the driest and wettest samples of soil, sodium chloride produces almost exactly the results calculated on the assumption that the salt is present entirely in the soil solution and does not change the soil structure appreciably. The discrepancy at 99 per cent vapor pressure is probably due to the failure of the method because the temperature control was not sufficiently rigid. The other discrepancy seems to indicate a modification in the physical condition of the solid phase. Calcium, magnesium, and aluminum chlorides also increase the water-absorbing power of the soil by an amount

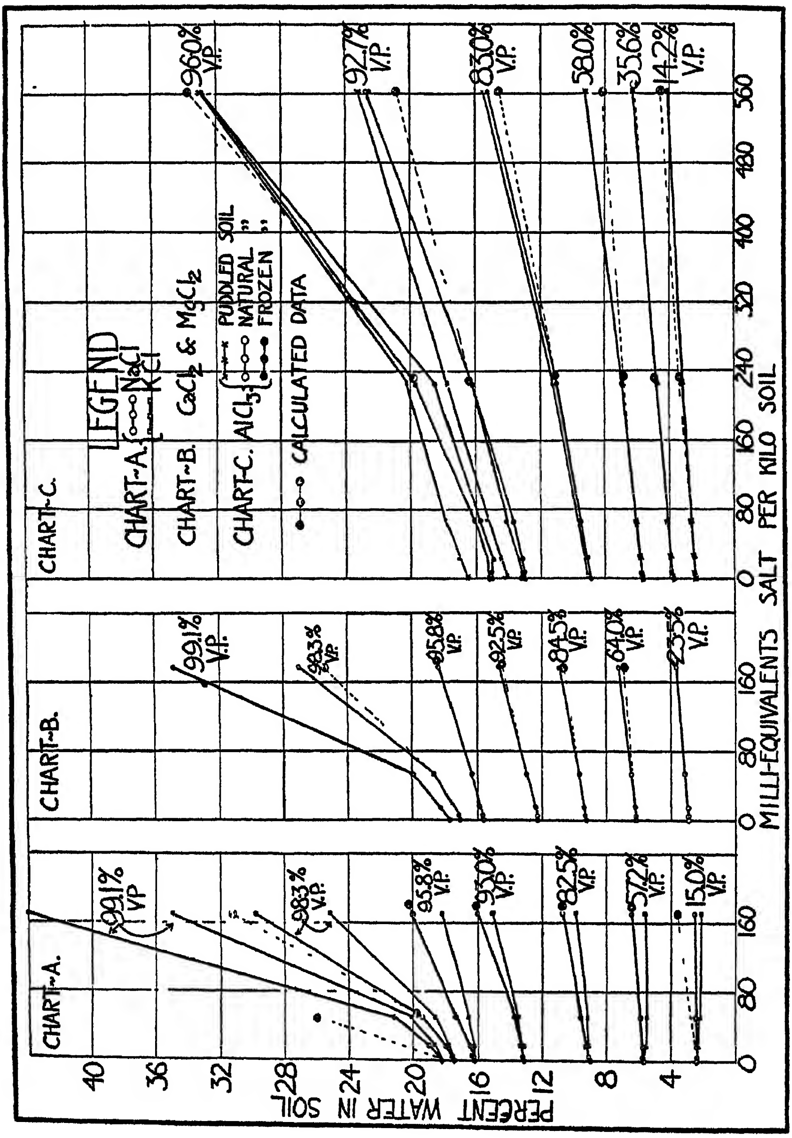


Fig. 2. Influence of Soluble Salts on the Moisture Absorption Power of Trenton Clay on Different Isobars

In Chart C the effect of freezing and puddling the soil are also indicated.

TABLE 3

Vapor pressure data for Trenton clay to which different salts were added

(See figure 2)

SALT ADDED	SALT CONCENTRATION M.E. PER KILO OF SOIL	VAPOR PRESSURE	WATER IN: Salt-free soil	WATER IN: Saline soil: Observed	WATER IN: Saline soil: Corrected	WATER IN: Saline soil: Calculated	VAPOR PRESSURE LOWERING: Found	VAPOR PRESSURE LOWERING: Calculated	SALT CONCENTRATION IN WATER (CALCULATED) EQUIVALENT PER 1000 GM.
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	
NaCl	50	98.3	17.45	19.45		19.40	0.8	0.8	0.25
	171	98.3	17.45	29.60		31.20	1.7	1.7	0.60
	171	95.8	16.20	19.92		19.80	3.0	2.8	0.90
	171	93.0	13.10	16.01		15.80	3.5	3.3	1.10
	171	82.5	9.02	10.77		10.60	5.0	5.1	1.60
	171	57.2	5.65	6.41		6.45	9.3	9.0	2.60
	171	15.0	2.37	2.59		3.63	3.5	18.0	4.75
KCl	171	98.2	17.45	25.20		31.20	1.7	1.7	0.60
	171	95.8	16.20	18.21		19.80	2.2	2.8	0.90
	171	93.0	13.10	15.12		15.80	2.5	3.3	1.10
	171	82.5	9.02	9.82		10.60	3.3	5.1	1.60
	171	57.2	5.65	5.65		6.35	0	8.5	2.70
	171	15.0	2.38	2.16		3.55	−3.5	15.8	4.85*
$CaCl_2$ or $MgCl_2$	177	98.3	17.10	27.15		25.40	1.7	1.7	0.70
	177	95.8	15.65	18.47		18.20	2.5	2.4	1.00
	177	92.5	12.30	14.75		14.70	2.9	2.9	1.20
	177	84.5	9.23	10.90		10.65	4.2	4.0	1.65
	177	64.0	6.14	7.24		6.90	10.0	6.8	2.60
	177	23.5	2.90	3.65		3.65	11.0	11.0	4.70
$AlCl_3$	223	96.0	15.26	19.67	18.90	19.00	2.8	2.8	1.2
	223	92.7	13.15	16.20	15.50	15.70	3.3	3.4	1.4
	223	83.0	8.85	11.00	10.60	10.70	4.8	5.0	2.1
	223	58.0	5.70	6.90	6.65	6.43	10.5	8.3	3.5
	223	35.6	3.75	4.75	4.60	4.70	10.0	11.5	4.7
	223	14.2	2.42	3.20	3.15	3.45	11.5	15.5	6.4
$AlCl_3$	562	96.0	15.26	33.00	31.20	33.60	4.0	4.0	1.7
	562	92.7	13.15	22.65	20.85	19.00	7.2	6.3	2.9
	562	83.0	8.85	15.20	14.20	13.50	11.5	10.0	4.0
	562	58.0	5.70	9.20	8.60	7.55	23.5	18.0	7.4
	562	35.6	3.75	6.30	5.95	5.83	25.0	23.0	9.7
	562	14.2	2.42	4.10	4.00	4.50	24.0	30.0	12.5

* Saturated.

closely approaching the theoretical value, and show only a slight tendency to change the soil structure, except in the case of the highest concentrations of the aluminum salt, in which the soil absorbs more water than estimated at inter-

mediate vapor pressures and less in the driest sample. It is possible that some of these differences are the result of erroneous calculations of the theoretical changes, caused by lack of vapor pressure data for calcium and magnesium chloride solutions, and further discussion would not be profitable at this time. The potassium chloride, on the other hand, increases the water absorption of

TABLE 4

Vapor pressure data for Trenton clay to which different salts were added

SALT ADDED	SALT CONCENTRATION M.E. PER KILO OF SOIL	VAPOR PRESSURE	WATER IN: Salt-free soil	WATER IN: Saline soil, Observed	WATER IN: Saline soil, Corrected	WATER IN: Saline soil, Calculated	VAPOR PRESSURE LOWERING: Found	VAPOR PRESSURE LOWERING: Calculated	SALT CONCENTRATION IN WATER (CALCULATED) EQUIVALENTS PER 1000 GM.
		per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	
Na_2CO_3	189	98.3	16.30	17.00		23.50	0.6	1.70	0.8
	189	96.8	15.16	16.08		17.00	1.0	2.30	1.1
	189	90.7	11.30	12.16		13.20	1.5	3.10	1.4
	189	65.2	6.37	6.24		6.95	−0.3	5.80	2.7
	189	34.8	3.67	3.30		4.45	−7.0	9.00	4.1
	189	16.0	2.53	2.19		3.30	−4.5	12.50	5.7
Na_2SO_4	227	96.2	15.60	16.60		19.20	1.2	3.00	1.2
	227	92.8	13.36	14.14		16.30	1.3	4.20	1.4
	227	83.9	9.52	10.00		12.00	1.9	7.00	1.9
	227	57.5	5.73	5.72		7.00	−0.1	14.00	3.2*
	227	36.5	3.78	3.75		5.05	−0.4	14.00	3.2+*
	227	16.5	2.61	2.43		3.50	−2.2	14.00	3.2+*
$Al_2(SO_4)_3$	182	98.2	17.30	17.60	17.00	20.00	−0.3	0.95	0.9
	182	96.0	15.10	15.57	15.00	16.30	−0.1	1.20	1.1
	182	93.0	13.00	13.30	12.70	14.00	−0.3	1.40	1.3
	182	79.4	8.43	8.73	8.43	8.75	0.0	2.20	2.1
	182	23.5	3.05	3.54	3.44	3.40	6.5	6.00	5.6*
$FeSO_4$	133	98.2	17.30	17.80	17.30	19.0	0.0	0.75	0.7
	133	96.0	15.10	15.85	13.35	16.0	0.2	0.90	0.8
	133	93.0	13.00	13.60	13.10	13.8	0.2	1.05	1.0
	133	79.4	8.43	8.72	8.40	8.7	0.0	1.70	1.6
	133	23.5	3.05	3.59	3.5	3.3	7.0	4.40	4.2*

* Saturated.

the soil by an amount decidedly less than that calculated and in the drier samples more water is taken up by the normal soil than when a high concentration of salt is present. When the behavior of the other chlorides is considered it is difficult to understand why potassium chloride should be partially removed from the soil solution, as the data seem to indicate. It will be shown in a later paper[2] that when potassium replaces the exchangeable bases in a

[2] Thomas, M. D. Aqueous vapor pressure in soil: IV. Soon to appear in *Soil Science*.

soil the water-absorbing power of the latter is considerably reduced. If some replacement of this kind occurs on adding the salt to the soil, the concentration of the soil solution will appear to be lowered, even though the equivalent concentration of electrolyte is not changed. This reaction will also serve to explain the behavior of sodium chloride, since at low vapor pressures sodium-saturated soil has a smaller water-absorbing power than a calcium soil, whereas at higher vapor pressures the values are nearly the same.

The data for the sulfates and sodium carbonate are analyzed in table 4 in a manner similar to that employed in table 3. When the experimental data were plotted, a series of nearly straight lines parallel to the X axis were obtained and it was not deemed worth while to present a graph of the data in detail. With all of these salts the water-absorbing power of the soil is increased only very slightly or is actually decreased because of their addition. The obvious explanation of these results is that the salts reacted with the soil, producing the relatively insoluble earth carbonates and sulfate. Spurway (3) has discussed this point. It is evident, however, that these salts exert a physical or chemical effect upon the soil in addition to the effect upon the concentration of the soil solution. This is particularly true at low moisture contents. Iron and aluminum sulfates appear to be completely precipitated from the soil solution without any other modification of system, but at the lowest vapor pressure an anomolously high absorption is shown. The behavior of the sodium sulfate and carbonate may be due to the precipitation of the anions, together with some base replacement, as suggested above. This question is being investigated further. The data explain why sodium sulfate in a saline soil is much less toxic to plants than sodium chloride, though equivalent concentrations of the two salts in solution culture are about equally toxic.

SUMMARY

1. Samples of Trenton clay were manipulated to simulate a thorough puddling and were also frozen, when the soil contained enough water to render it plastic, and the vapor pressure moisture relations of the materials were studied.

2. Puddling the clay increased its water-absorbing power at vapor pressures above 85 per cent. Freezing had the opposite effect. When the soil was dried further, these differences disappeared, but returned when the soil was moistened again.

3. Calculation by means of the thermodynamic capillary equation indicated that the smallest capillary spaces affected by these treatments had a size range from about 5 to 25 millimicrons radius.

4. Addition of the chlorides of Na, Mg, Ca, and Al modified the water-absorbing power of the soil by an amount which could be calculated on the assumption that the salt was entirely in solution and did not exert any influence on the soil.

5. Potassium chloride appeared to be partially absorbed from the soil solu-

tion but it may have reacted with the replaceable bases in the soil, giving a potassium silicate complex which has a lower water-absorbing power than the natural soil, thus indicating a reduction in the concentration of the soil solution which did not occur. This question is being investigated further.

6. Sulfates and carbonates were precipitated by the soil and largely removed from the soil solution. There is some evidence of base replacement in these reactions also.

REFERENCES

(1) Anderson, M. S., and Mattson, S. 1926 Properties of colloidal soil material. U. S. Dept. Agr. Bul. 1452.

(2) Leopold, H. G., and Johnston, J. 1927 Vapor pressure of the saturated aqueous solutions of certain salts. *Jour. Amer. Chem. Soc.* 49: 1974.

(3) Spurway, C. H. 1926 The effect of the nature of the exchangeable bases on the retention of anions by soils. *Jour. Amer. Soc. Agron.* 18: 497–505.

(4) Svedberg, T., and Nichols, J. B. 1923 Determination of size and distribution of size of particle by centrifugal method. *Jour. Amer. Chem. Soc.* 45: 2910–2917.

(5) Thomas, M. D. 1924 Aqueous vapor pressure of soils: II. *Soil Sci.* 17: 1–18.

ERRATA

Carbon dioxide evolution of soil and crop growth, by H. Lundegardh

Soil Science, vol. XXIII

Page 420—In this paper, the formula for the calculation of the soil respiration has been mis-written, 10 being omitted in the denominator. The formula should be

$$\frac{(a - b) \times 1.858 \times V \times \frac{60}{t}}{10 \times F} = \text{gm. } CO_2 \text{ (to the hour for each square meter)},$$

where a is the CO_2-concentration in the bell-air at the beginning, b the same at the end, calculated in per cent, t the time in minutes, 1.858 the weight of 1 liter CO_2 at 15°C., V the volume in cubic centimeters of the respiration bell, F the soil surface under the bell in square centimeters.

The values of soil respiration, given in the paper, have been calculated by the correct formula.

The direct method in soil microbiology and its application to the study of nitrogen fixation,

by S. Winogradsky

Soil Science, vol. XXV

Page 40—Sixth line from bottom—The ratio should read *2.5:100* instead of *25:100*.

Phosphate in the soil solution as affected by reaction and cation concentrations,

by L. J. H. Teakle

Page 162—Citation (28) should read: Wrangell, M. von 1926 Über Bodenphosphate und Phosphorsäurebedürftigkeit. *Landw. Jahrb.* 63: 627–668.

REPLACEABLE BASES AND THE DISPERSION OF SOIL IN MECHANICAL ANALYSIS

MOYER D. THOMAS

Utah Agricultural Experiment Station

Received for publication January 30, 1928

During the last six years many papers have appeared dealing with the single subsidence methods of mechanical analysis of dispersions. These methods are based either on the original Odén procedure of measuring the rate of accumulation of the sediment, which indicates the rate of change of concentration of the solid phase in the whole body of suspension; or on the simpler principle of determining the rate of change of suspension density in a thin stratum of the liquid at a known distance below the surface, as exemplified in Wiegner's specific gravity method, in Robinson's single pipette or the Utah multiple pipette method, and in Svedberg's centrifugal methods (6). The subject has recently been reviewed by Odén (5).

On the basis of extensive experience, as well as the evidence in the literature, it can be stated confidently that these methods are capable of giving accurate information concerning the size distribution in a soil suspension, which is stable over the period of analysis, but we have no assurance that the results offer an accurate representation of the soil itself, on account of the difficulties attending the dispersing of the solid material. The experience of the workers in the Bureau of Soils (1) and of Joseph (3, 4) illustrates this point. The former were not able to reach an end point in the separation of colloidal material when they repeatedly subjected fine silt to the dispersing process. The latter believes that the greater part of the particles smaller than 1μ radius can be colloidally dispersed. Weigner (8) has pointed out a number of difficulties attending the dispersion process with different mechanical and chemical treatments. It is evident that this phase of the problem is not in a satisfactory condition. This paper is presented to show the influence of different replaceable bases on the dispersion of soil.

EXPERIMENTAL

The materials studied are described in a preceding paper (7). They were subjected to preliminary treatment for mechanical analysis as follows:

Two grams of the air-dried soil was shaken with 400 cc. 0.5 per cent sodium carbonate for about 8 hours, 60 cc. of water was added, and shaking was continued for about 16 hours. The suspension was then diluted to 800 cc., and the mechanical analysis conducted according to the method developed at this Station (2).

In some preliminary work it was found that the dilution of the carbonate solution to 0.2 per cent concentration, as described, resulted in appreciably greater dispersion than 24 hours' shaking with 0.5 per cent solution; therefore, this procedure was adopted uniformly throughout the study. It seems likely that the English method of shaking the fully diluted solution for a long time would produce somewhat greater dispersion still, but that technique was not tried. Neither was Robinson's hydrogen peroxide treatment employed, because only one of the soils contained an appreciable amount of organic matter. Some of the samples were also shaken for 24 hours with 100 cc. of distilled water, no sodium carbonate being added. The results are given graphically in figures 1, 2, and 3, the percentage of material smaller than a given radius being plotted against the radius as abscissa on a logarithmic scale. A uniform method of representing the results is maintained in all the figures. The different bases are described by the points as shown in the legend of figure 2. The solid lines represent the results when sodium carbonate is added as a deflocculating agent. The broken lines, the points of which have a circle around them, give the results without a deflocculating agent. The values of the ordinates corresponding to four different abscissae are summarized in table 1.

Figure 1 contains the data for the colloidal mineral 1296 and shows very strikingly a wide range of dispersion produced by changing the replaceable bases in this material. The data for the sodium-saturated material indicate that the mineral is practically entirely colloidal in nature, about 90 per cent of it having particles smaller than 0.1μ radius. It will also be observed that the addition of sodium carbonate reduces somewhat the dispersion of this material. All the other samples of 1296 show marked flocculation, the most dispersed being the untreated material which contains a considerable amount of replaceable sodium.

The addition of sodium carbonate increases the dispersion slightly in the case of the ammonium-saturated mineral and very markedly in the case of the calcium-saturated material. The magnesium colloid on the other hand is thrown down almost completely as very fine silt by the addition of sodium carbonate. In this case it seems likely that the salt brings into solution an appreciable amount of magnesium ions, which cause the flocculation. The sodium carbonate doubtless reacts with the calcium sample also, replacing some calcium, which is then precipitated as carbonate, and rendered ineffectual as a flocculating agent. The potassium mineral, like the sodium mineral, is somewhat less completely dispersed by the addition of sodium carbonate.

The wide range of dispersion shown by this colloid suggests the desirability of producing sodium saturation of the colloids of soil as a preliminary treatment in the mechanical analysis.

In figure 2 are presented the results for the 4 Utah soils. It will be observed that the effect of different replaceable bases is appreciable, but much smaller than in the case of the 1296. The calcareous Trenton clay (chart C) shows the greatest dispersion in the case of the sodium- and potassium-treated soil to

TABLE 1

Per cent of material smaller than four particular sizes as indicated by mechanical analysis when the replaceable bases of the soil are exchanged for a single base

BASE INTRODUCED	Na_2CO_3 ADDED AS DEFLOCCULATING AGENT									NO DEFLOCCULATING AGENT ADDED					
	T1	1170	1170A	1171	1286	1293	1294	1295	1296	T1	1171	1286	1293	1294	1296
Upper size limit—10 microns radius															
H	..	69	..	86	62	..	90	84	..	..	71	..	71	67	..
Na	92	69	98	85	63	83	92	85	..	92	73	66	82	92	..
K	92	69	99	85	63	82	89	84	..	90	85	63	71	82	..
NH_4	..	69	96	73	60	82	89	84	..	..	..	..	..	88	..
Ca	91	69	99	83	63	82	89	83	..	..	..	..	73	72	93
Mg	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Al	..	..	98	..	60	..	..	..	..	..	..	..	..	..	..
U*	92	..	..	86	62	82	89	84	..	..	82	..	..	69	..
Upper size limit—2.5 microns radius															
H	..	42	..	67	39	42	78	57	..	..	46	..	23	49	..
Na	78	42	96	67	37	44	79	62	96	76	51	42	45	79	99
K	77	42	95	66	34	37	75	57	92	72	61	36	30	71	87
NH_4	..	42	96	57	36	42	75	57	90	..	..	..	..	68	90
Ca	78	42	96	67	34	42	75	58	91	56	..	..	28	53	88
Mg	..	..	..	..	..	..	..	..	96	..	..	..	..	..	89
Al	..	..	97	..	34	..	..	..	..	..	..	..	..	..	..
U*	78	..	..	67	37	42	75	57	92	..	58	..	..	53	..
Upper size limit—0.5 micron radius															
H	..	19	..	50	26	25	63	48	..	..	23	..	6	25	..
Na	47	19	80	43	25	30	63	52	95	45	28	33	31	63	96
K	44	15	74	37	19	14	58	42	62	37	35	16	8	43	54
NH_4	..	21	85	37	20	23	59	48	74	..	..	..	..	36	61
Ca	47	16	70	36	21	25	60	48	78	25	..	..	10	23	49
Mg	..	..	..	..	..	..	..	..	3	..	..	..	..	..	59
Al	..	..	88	..	21	..	..	..	..	..	..	..	..	..	..
U*	47	..	..	37	23	23	61	48	79	..	23	..	..	25	..
Upper size limit—0.1 micron radius															
H	..	8	..	27	14	14	46	37	..	..	7	..	2	3	..
Na	19	8	23	17	14	16	46	39	83	4	11	23	19	46	91
K	16	1	19	15	5	1	23	19	9	7	11	5	3	10	19
NH_4	..	10	34	18	9	6	41	33	27	..	..	..	..	8	21
Ca	14	0	14	14	4	10	38	33	43	3	..	..	3	3	9
Mg	..	..	..	..	..	..	..	..	0	..	..	..	..	..	14
Al	..	..	42	..	5	..	..	..	..	..	..	..	..	..	..
U*	19	..	..	16	9	6	4	36	52	..	5	..	..	3	..

* Untreated.

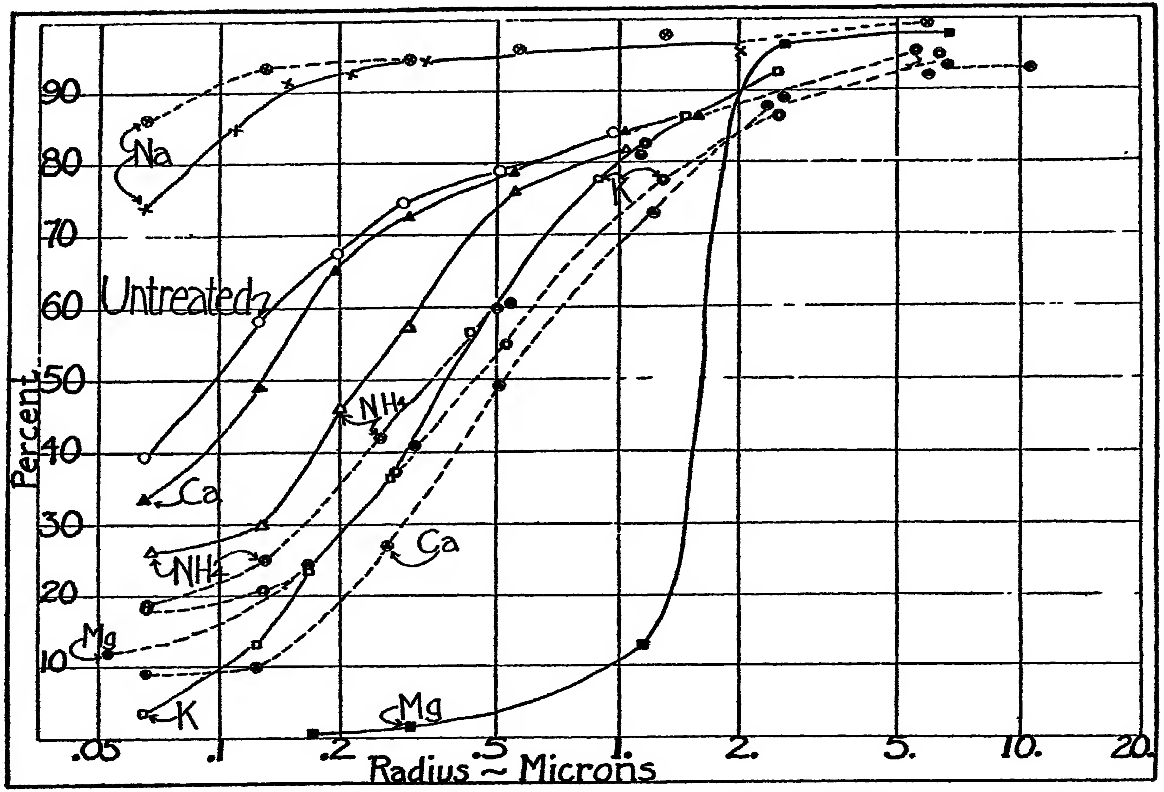


FIG. 1. SIZE DISTRIBUTION CURVES FOR THE COLLOID 1296 IN WHICH THE REPLACEABLE BASES HAVE BEEN EXCHANGED FOR A SINGLE BASE.

Th ordinate shows the percentage of the material smaller than the size indicated by the corresponding abscissa.

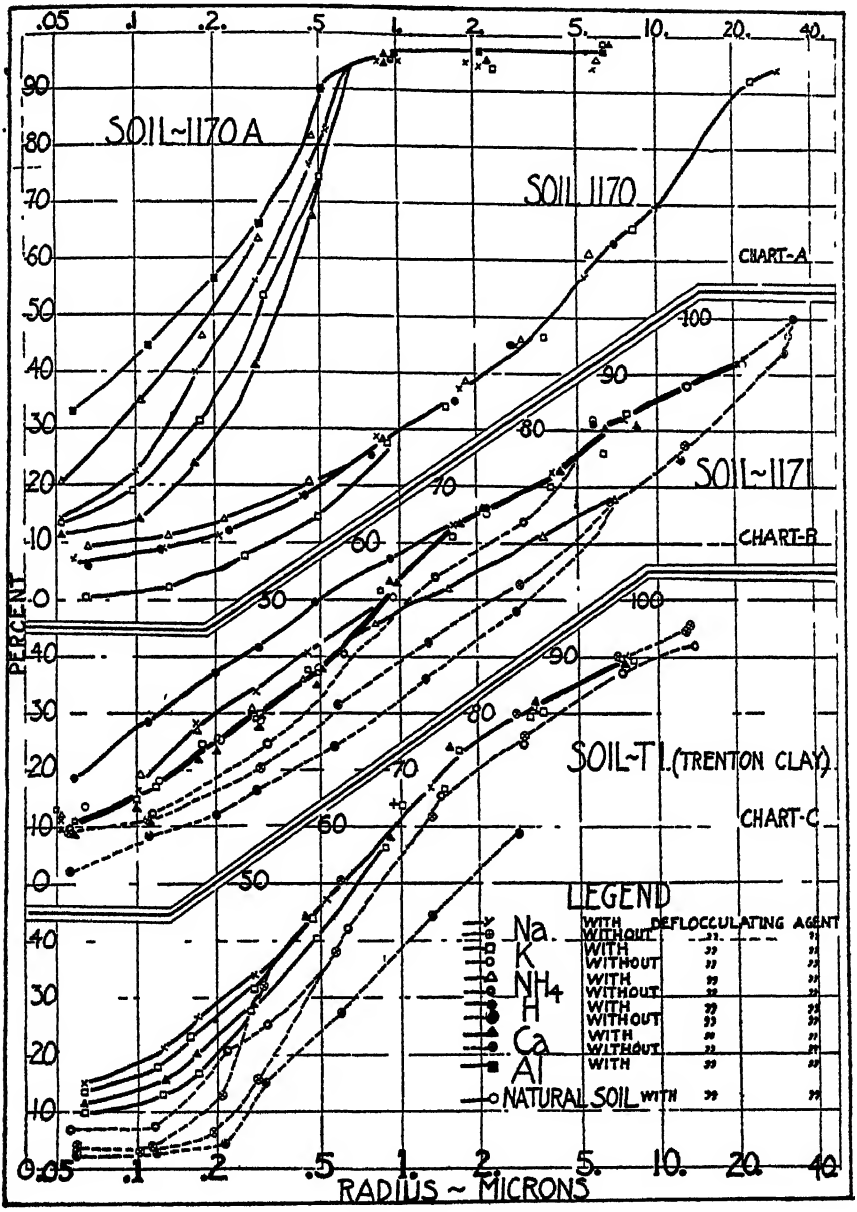


FIG. 2. SIZE DISTRIBUTION CURVES FOR THE UTAH SOILS, IN WHICH THE REPLACEABLE BASES HAVE BEEN EXCHANGED FOR A SINGLE BASE.

The ordinate represents the percentage of material of radius smaller than the value of the corresponding abscissa.

which a deflocculating agent was added. In all cases the addition of sodium carbonate increases the dispersion of the soil. It was shown in a preceding paper (7), however, that in the preparation of the sodium- and potassium-treated samples of Trenton clay there was a large amount of hydrolysis of the mineral silicates producing alkali hydroxide and carbonate when the excess of neutral salt was washed out. It is evident, therefore, that the material as finally prepared was not completely saturated with sodium or potassium. Two different preparations of the NaCl-treated mineral were analyzed. These showed somewhat different results due to unequal amounts of hydrolysis in the washing process.

In chart B the data for soil 1171 indicate that the most effective treatment was hydrochloric acid, followed by the addition of sodium carbonate. In this soil calcium carbonate evidently plays an important part. The untreated soil contains 1.15 per cent carbonate CO_2. This was practically all removed both by the acid and by the ammonium chloride treatment. The sodium and potassium treatments on the other hand did not reduce it appreciably and there was considerable hydrolysis when the excess of salt was removed. These data suggest the wisdom of removing small amounts of lime by a preliminary acid treatment before attempting to effect dispersion. Such a treatment would of course be out of the question with a soil like Trenton clay, which contains over 30 per cent of calcium and magnesium carbonates.

Chart A shows the non-calcareous soil 1170 and a mechanical separate from this soil, 1170-A. The results with both these materials are anomolous because the ammonium and aluminum treatments give greater dispersion than the sodium treatment. The acid digestion of 1170 followed by sodium carbonate gives the same result as sodium replacement. In the case of 1170-A an analysis of the acid-treated soil using the deflocculating agent gave a result identical with the sodium-saturated material, but these values were not obtained under conditions comparable to the other experiments and they are, therefore, discarded. It is not clear why the ammonium and aluminum soils were the most completely dispersed. A suggestion as to the cause is found in table 4 of the preceding paper (7), in which it is seen that the sodium, potassium, and calcium preparations were accomplished with the solution of considerably smaller amounts of calcium and magnesium than was yielded by the ammonium, aluminum, and acid treatments. The difference was due to the solution by the latter of the earth silicates which may have exerted a flocculating effect on the sodium- and potassium-treated dispersions. The aluminum salt itself probably has no particular influence on the final result, apart from its acidity, since in soil 1286 (fig. 3) the aluminum treatment produces a dispersion similar to potassium replacement.

The data for the non-calcareous soils from California, Oregon, Missouri and Alabama are presented in figure 3. The heavy Oktibbeha clay, 1294, in chart D, shows increased dispersion due to the addition of sodium carbonate in every case, except with the sodium-saturated soil, in which the results are the same

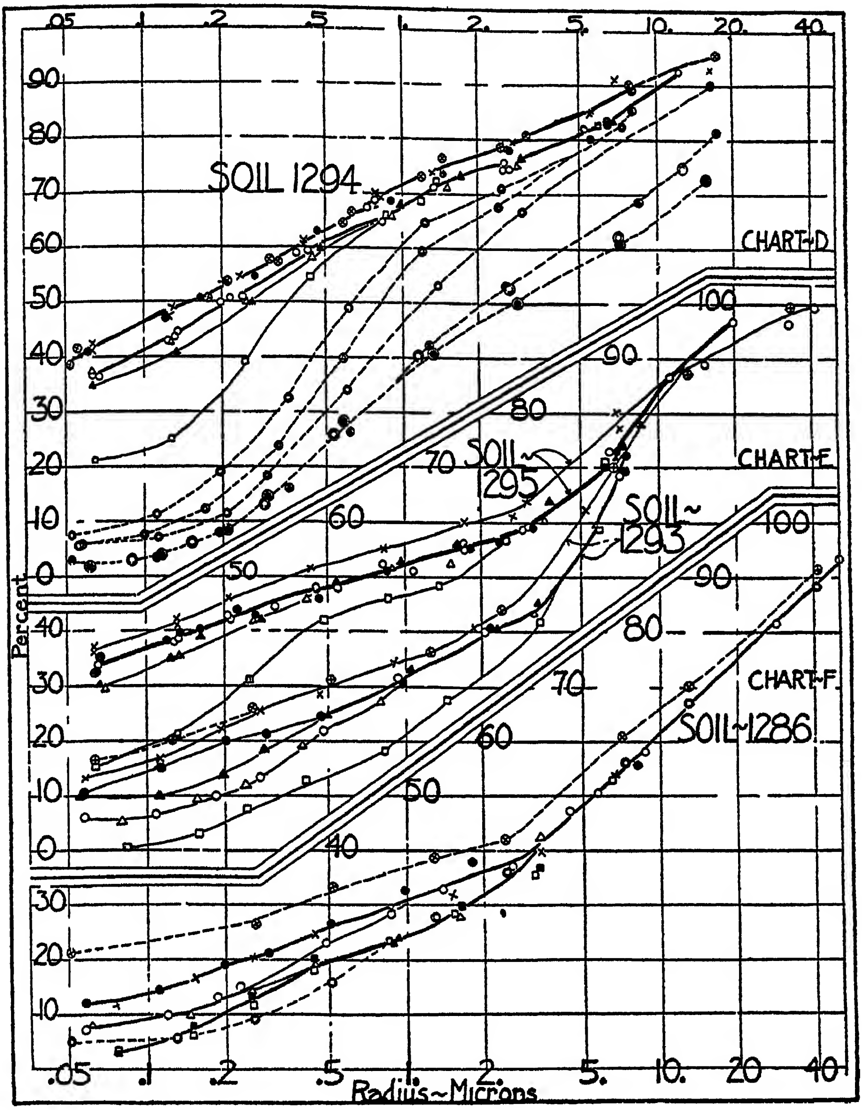


FIG. 3. SIZE DISTRIBUTION CURVES OF FOUR SOILS IN WHICH THE REPLACEABLE BASES HAVE BEEN EXCHANGED FOR A SINGLE BASE.

The ordinate shows the percentage of material of radius smaller than the value of the corresponding abscissa. Legend same as in figure 2.

whether sodium carbonate is added or not. The hydrochloric acid treatment of this soil, followed by the addition of sodium carbonate gives the same dispersion as is shown by the sodium-saturated soil. The potassium-saturated sample with a deflocculating agent gives the least complete dispersion.

The other three soils show maximum dispersion as a result of the sodium treatment, although in the case of 1286 the addition of sodium carbonate does not give so complete a deflocculation as is produced without it. In these soils also the acid digestion, followed by the sodium carbonate, does not give quite so complete a dispersion as the sodium-saturation treatment.

As far as it is possible to draw conclusions from the data presented, it is evident that the maximum amount of dispersion it to be obtained in the majority of cases by producing sodium saturation in the soil mass. In many cases this can be in effect accomplished by a preliminary treatment with dilute acid followed by the addition of sodium carbonate. The presence of the electrolyte, however, is not always without detrimental effect. It would not, however, be practicable as a routine method of mechanical analysis to subject the sample to a treatment necessary for complete replacement of its bases with sodium because the subsequent washing process is very difficult to carry out, and a treatment with dilute acid followed by the addition of sodium carbonate, therefore, appears to be the most promising of those suggested by the data in this paper, for non-calcareous soil.

SUMMARY

1. A number of soils from widely separated localities, together with a colloidal mineral, all of which had been treated with neutral salts or .05 N HCl to exchange their replaceable bases for a single base, were subjected to the mechanical analysis process, with and without Na_2CO_3 as a deflocculating agent.

2. In most cases the sodium-saturated soil was the most completely dispersed.

3. The addition of the deflocculating agent to the sodium-treated soil either did not increase the dispersion or actually decreased it, except in the case of the calcareous soils, which when the soluble salt was washed out, had lost by hydrolysis a considerable portion of the sodium introduced.

4. In some cases a preliminary treatment with .05 N HCl, followed by a removal of the soluble material and subsequent use of Na_2CO_3 as deflocculating agent, gave as complete a dispersion in the mechanical analysis as was obtained with the sodium-saturation treatment.

5. Two cases are noted in which the ammonium-treated material dispersed more completely than did the sodium treatment and in one case maximum dispersion was obtained with the sample which had been treated with aluminum chloride.

6. The dispersion of the calcium-saturated sample was increased markedly by the addition of the deflocculating agent, but the reverse was true of the magnesium mineral.

7. In view of the experimental difficulty attending the preparation of sodium-saturated soil it seems likely from these data that the best routine method of dispersing the soil sample for mechanical analysis would consist in preliminary treatment with dilute acid followed by the use of sodium carbonate as the deflocculating agent.

REFERENCES

(1) ANDERSON, M. S., ET AL. 1922 Absorption by colloidal and non-colloidal soil constituents. U. S. Dept. Agr. Bul. 1122.

(2) JENNINGS, D. S., THOMAS, M. D., AND GARDNER, W. 1922 A new method of mechanical analysis of soils. *Soil Sci.* 14: 485–499.

(3) JOSEPH, A. F. 1925 Clays as soil colloids. *Soil Sci.* 20: 89–94.

(4) JOSEPH, A. F. 1927 Determination of soil colloids. *Soil Sci.* 24: 271–274.

(5) ODÉN, S. 1925 The size distribution of particles in soils and experimental methods of obtaining them. *Soil Sci.* 19: 1–36.

(6) SVEDBERG, T., AND RINDE, H. 1924 The ultra-centrifuge, a new instrument for the determination of size and distribution of size of particle in amicroscopic colloids. *Jour. Amer. Chem. Soc.* 46: 2677–2693.

(7) THOMAS M. D. 1928 Replaceable bases in some soils from arid and humid regions. *Soil Sci.* 25: 379–392.

(8) WIEGNER, G. 1927 Method of preparation of soil suspensions and degree of dispersion as measured by the Wiegner-Gessner apparatus. *Soil Sci.* 23: 377–390.

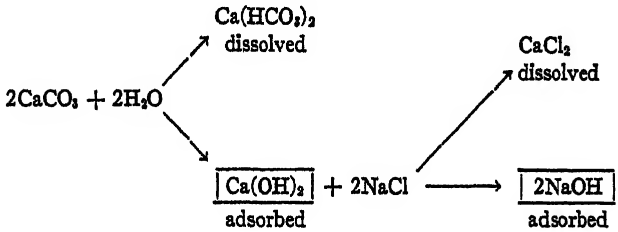
THE $CaCO_3$-SOIL EQUILIBRIUM AND THE LIME REQUIREMENT

SANTE MATTSON

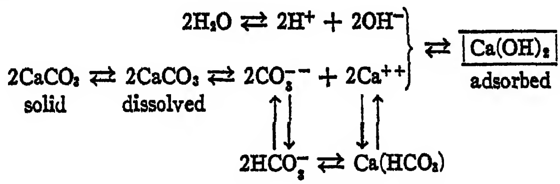
Bureau of Soils, U. S. Department of Agriculture

Received for publication February 28, 1928

In a recent paper Prianishnikow and Golubev (3) observed that when $CaCO_3$ is added to a soil in the presence of water a certain mount of Ca is adsorbed by the soil and that the liberated CO_2 causes an equivalent quantity of Ca to pass into solution as $Ca(HCO_3)_2$. This action of the soil on the carbonate and the equivalence between the adsorbed Ca and the Ca left in solution as bicarbonate were observed by the author several years ago (1). On adding $CaCO_3$ and water to a sample of clay (which had been rendered unsaturated by a previous treatment with dilute HCl and thoroughly washed) a certain amount of Ca was found to pass into solution. On adding $CaCO_3$ and normal NaCl instead of water the quantity of Ca found in solution was almost exactly twice as large. The reaction was represented by the following scheme:



The $Ca(OH)_2$ formed by hydrolysis of the carbonate is adsorbed by the soil material until a state of equilibrium is attained, which is better illustrated by the following equilibrium reaction:



The reaction is displaced toward the right until the soil material is saturated.

This equilibrium between the soil and the $CaCO_3$ is of the greatest importance because it insures a saturated condition of the soil material and establishes a reaction favorable for plant growth. It is this equilibrium which is approached if not attained, whenever a soil is limed. The magnitude of the displacement

in the above reaction which takes place when $CaCO_3$ is added to a soil represents the degree of unsaturation of the soil and constitutes a most direct and natural measure of the lime requirement.

The quantity of $CaCO_3$ decomposed by a soil might be found by determining the quantity of liberated bicarbonate, or the adsorbed Ca, which is equivalent to the bicarbonate, might also be determined by displacement with NaCl. In the latter case the displaceable Ca originally present in the soil would naturally have to be deducted from the quantity of Ca found in the NaCl extract of the $CaCO_3$-treated soil.

Since $CaCO_3$ must be added in considerable excess to insure an equilibrium, the chief difficulty in the above method would be the appreciable solubility of the carbonate in water and especially in NaCl solution. It occurred to the author, therefore, that the displacement in the above reaction between a soil and $CaCO_3$ might be determined without allowing the carbonate to come in actual contact with the soil. For this purpose conical bags of thin parchment paper were made by folding the latter like an ordinary filter. Samples of 1 gm. each of electrodialyzed Sharkey soil colloidal material (2) were placed in a series of such bags together with sufficient water completely to saturate and cover the soil material. The bags were then placed in a soft paste of pure $CaCO_3$. After 1, 3, 7, 8, and 14 days, respectively, a bag was removed from the paste, its content placed on the filter and the adsorbed Ca, displaced with N NH_4Cl solution, was gravimetrically determined. The results are shown in table 1.

TABLE 1

Quantities of Ca adsorbed by electrodialyzed Sharkey soil colloidal material from a $CaCO_3$ paste through a parchment membrane

	TIME OF CONTACT WITH PASTE				
	1 day	3 days	7 days	8 days	14 days
Ca adsorbed, *milliequivalents per gram*	0.282	0.591	0.697	0.690	0.682

It is evident that, under the conditions of the experiment, a period of 7 days is sufficient for the $CaCO_3$-soil equilibrium to be established through a parchment membrane even when the soil material is, at the outset, completely unsaturated as in the above case. The quantities of Ca adsorbed is in close agreement with the quantities of mono- and divalent cations (Mn, Ca, Mg, K, and Na) removd by electrodialysis, by displacement with NH_4Cl, and by treatment with 0.05 N HCl from the original Sharkey soil, which represents a well saturated, nearly neutral soil material. The quantities of exchangeable cations removed from the original material by the above three methods were 0.712, 0.698, and 0.746 milliequivalents per gram respectively (2). The experiment shows that the quantity of Ca adsorbed by the soil material from

$CaCO_3$ is a measure of the degree of unsaturation and therefore also of the lime requirement.

If the above method should prove applicable to all kinds of soils it would be of great value in determining the degree of saturation and the lime requirement of soils.

REFERENCES

(1) MATTSON, S. 1922 Die Beziehungen zwischen Ausflockung, Adsorption und Teilchenladung mit besonderer Berücksichtigung der Hydroxylionen. *Kolloidchem.* 14: 227–316.

(2) MATTSON, S. 1926 Electrodialysis of the colloidal soil material and the exchangeable bases. *Jour. Agr. Res.* 33: 553–567.

(3) PRIANISHNIKOV, N., AND GOLUBEV, M. 1927 The decomposition of carbonates and phosphates by the soil acidoids. Abs. Proc. First Internatl. Cong. Soil Sci. Comm. II, Washington.

FUNGI IN SOME COLORADO SOILS

E. L. LeCLERG and FREDERICK B. SMITH[1]

Colorado Agricultural College

Received for publication March 2, 1928

The fungi in Colorado soils have received but slight consideration, and little is known of their occurrence in the soils of that state. Colorado presents conditions and a variety of soils not found in regions where such studies have been carried on. The following investigations were undertaken, therefore, to ascertain the fungi common to Colorado soils, and to determine whether soils of different types collected under different conditions of depth, moisture, and soluble salts contain characteristic groups of fungi.[2] It is not the purpose of this work to describe any new forms of fungi, but to list the species occurring in Colorado soils and to attempt to associate known forms with soil types and conditions.

Brown (2) states that "different soils undoubtedly have different fungus floras," and that the relative occurrence of active and spore forms of various organisms may vary in the *same* soil with varying conditions of moisture, aeration, reaction, and food supply. Waksman (14) found no distinct difference between the species of fungi from cultivated and uncultivated soils. However, he states that "each soil seems to have a more or less characteristic fungus flora." Dale (3, 4) studied the fungous flora of sandy, chalky, uncultivated peat, and "black earth" soils and found specific differences, although many of the species were common to all of these soils. Goddard (6) found the fungous flora of different soils to be quite uniform. Werkenthin (19) isolated the same species of fungi from cultivated and virgin soils. He concluded that cultivation had not changed the fungous flora of these soils.

The results reported on the distribution of species of fungi at different depths of the soil are confusing. Goddard (6) found fungi to be quite uniformly distributed down to 14 cm. Werkenthin (19) reported similar results, finding the same species from 1 to 4 inches. Below 4 inches no viable spores were found. Waksman (15) found *Zygorhynchus vuilleminii* to be predominant down to 30 inches. It was often the only species found below 12 inches.

[1] Assistant plant pathologist and formerly associate agronomist Colorado Agricultural Experiment Station, now assistant chief in soil chemistry and bacteriology, Iowa Agricultural Experiment Station, respectively.

[2] The writers wish to acknowledge with pleasure their indebtedness to Dr. L. W. Durrell for suggestions and assistance given during the course of the work; to Dr. H. M. Fitzpatrick of Cornell University for aid in identifying some of the fungi; to Prof. Alvin Kezer and Dr. P. E. Brown for reading the manuscript.

Taylor (11) reported *Fusarium* at a depth of 24 inches. Rathbun (9) found *Zygorhynchus vuilleminii* present in every inch down to 44 inches, except from 30 to 32 inches. Russell (10) isolated 20 species at a depth of 1 inch, 19 species at a depth of 6 inches, and 11 species at a depth of 12 inches of soil on an unmanured grass plot. Paine (8) found the frequency of occurrence of fungi to decrease markedly with increase in depth below 3 inches.

EXPERIMENTAL DATA

Twenty-seven soils were collected from different parts of the state and where the soils have been mapped by the Bureau of Soils, samples were taken from definite soil types. Surface samples were taken from 0 to 7 inches and subsurface samples from 8 to 20 inches deep. In many fields, on the same soil type, local areas varying from a few square feet to two or three acres were found either barren or to some degree less productive than the adjacent parts of the field. For convenience such areas have been designated as productive and unproductive without any intention of giving more than a relative measure of the productive power of these soils.

Soils 1, 2, 3, and 4 have been mapped by the Bureau of Soils[3] as Prowers clay loam, described as a brown clay loam to a depth of 10 to 12 inches, and a lighter brown color to a depth of 5 feet or more. The texture from 15 to 30 inches below the surface is slightly heavier than the surface horizon and in places has small whitish spots of lime accumulation.

The field from which samples 1, 2, 3, and 4 were taken was in alfalfa in 1918. A small area died out and the area has increased in size each year. Every crop has died out on this area in the same manner, except sugar beets, which made some growth at first but turned black and died before maturity. Adjacent areas of the field on the same soil type have produced good crops every year.

Samples 1 and 2 were taken from the surface and subsurface, respectively, of the productive part of this field, and samples 3 and 4 were taken from the unproductive area.

Soils 40 and 41 have been mapped as Rocky Ford loam and described as a deep, fine-textured loam with a well-drained, deep sandy subsoil slightly heavier in texture from 10 to 30 inches below the surface. The color of the surface 10 inches is dark brown with a uniform lighter brown below this depth. Soil 40 is a surface sample of an unproductive area of the Rocky Ford loam and 41 is a surface sample taken from an adjacent productive area of the same type.

Soils 38 and 39 were taken from fields in the non-irrigated section of central eastern Colorado. Sample 38 represents the surface soil in an unproductive field. The surface soil of this field is a dark brown, stiff clay. Soil 39 is a light brown, very fine sandy loam from a productive field.

Soils 154, 82, 187, and 296 were taken from fields in the Republican River

[3] Sweet, A. T. Unpublished data. U. S. Dept. Agr. Bur. Soils.

Valley. Soil 154 represents the surface, and 82, the subsurface, of a productive yellowish-gray sandy loam. Samples 187 and 296 were taken from the surface and the subsurface respectively on an unproductive, stiff, yellow clay upon which all crops have made but poor growth since it was brought under cultivation.

Numbers 90, 91, 94, and 95 represent two soil conditions in northeastern Colorado on non-irrigated farms. Soils 90 and 91 were taken on areas of level lowlands. The surface soil, 90, is a dark brown silty clay, and the subsurface soil, 91, is light brown silt. Areas of this soil are uniformly unproductive, and good tilth is maintained only with difficulty. Soils 94 and 95 represent the high, level areas of productive land. The texture of the surface and subsurface is a uniform fine loam, and the color is dark to light brown.

Local areas of a black clay were found in lower areas of 90 upon which most crops, especially corn, do poorly. Soils 50 and 120 are surface and subsurface samples, respectively, of this area.

The non-irrigated region of north central Colorado is represented by soils 166, 178, 173, and 181. Sample 166 was taken from the surface and 178 from 12 to 18 inches deep on virgin medium sand. Sample 173 was from the surface and 181 from 12 to 18 inches deep on a cultivated area of this soil.

Soils 213 and 218 were taken from the surface and subsurface respectively of a dark brown silt loam found on the low, level areas of uplands north of the Cache la Poudre River.

Samples 206 and 196 were taken from the surface and 40 to 42 inches deep on virgin, alluvial brown sand. Number 197 represents the surface of a virgin residual soil derived from red sandstone. The soil is a uniform red sand.

Total soluble salts were determined by the official method, except that 25-cc. instead of 50-cc. aliquots were taken for evaporation. The moisture content was determined on the air-dry soil by drying 25 gm. in the oven at 110°C. for 5 hours. The figures in table 2 are the results of closely agreeing duplicates.

All samples were taken either with a sterile trowel or a soil auger which was fitted with a steel sleeve. The sampler was sterilized with mercuric chloride (1:1000). The top layer of soil, about one inch, was removed with a sterile spatula before the sample was taken. The samples were carried into the laboratory in sterile, air-tight tin containers or in sterile mason fruit jars. Dilution plates were poured immediately, usually the same day the samples were taken. Ten grams of each sample were placed in 300 cc. of sterile tap water and shaken thoroughly. Dilutions were made up to 1:30,000. One cubic centimeter of this dilution was poured into a sterile Petri dish, and the plates were poured in the usual way. The plates were incubated at 22–23°C. for 72 hours. After the incubation period, the plates were examined and transfers made from the different types of colonies to agar slants of Czapek's medium. In order that the present work might be comparable with that of others, media used by other investigators were chosen. Waksman's medium (18) was used for all isolation work, and pure cultures were maintained on Czapek's medium. The

gelatin media and the bean agar media of Thom (12) were also used in the identification work.

The species of fungi listed in table 1 represent the most common and most conspicuous members of the fungous flora so far found in Colorado soils. In determining these species particular use has been made of the work of Thom (12), Thom and Church (13), Jensen (7), Waksman (14, 16), Abbott (1), and Gilman and Abbott (5).

It may be noted in the table that 22 species representing 11 genera were isolated from Colorado soils during the course of this work. Of these 22 species 14 belong to the genera *Aspergillus*, *Penicillium*, and *Trichoderma*.

TABLE 1

Fungi isolated from Colorado soils

Aspergillus niger van Tiegh.
Aspergillus glaucus Link
Cephalosporium sp.
Fusarium sp.
Hormodendrum pallidum Oud.
Macrosporium sp.
Penicillium chrysogenum Thom
Penicillium duclauxi Delacroix
Penicillium expansum (Link) Thom
Penicillium funiculosum Thom
Penicillium intricatum Thom
Penicillium lilacinum Thom
Penicillium roseum Link
Penicillium No. 50
Penicillium No. 55
Penicillium No. 67
Rhizopus nigricans Ehrenb.
Spicaria simplicissima Oud.
Stachybotrys cylindrospora Jensen
Trichoderma lignorum (Tode) Harz
Trichoderma glaucum Abbott
Verticillium terrestre (Link) Lindau

DISCUSSION

From a consideration of the data presented in table 2, together with the description of the soils from which the organisms were isolated, it is seen that the conditions of the soil studied, such as total soluble salts, moisture content, texture, and relative productivity, bear little if any relation to the organisms found. However, if the samples had been taken when the soil contained more or less moisture, a different grouping of the organisms would undoubtedly have been found.

Aspergillus glaucus Link.

Aspergillus glaucus was isolated from a productive soil of low moisture content. The genus *Aspergillus* comprises one of the most numerous groups of fungi found in southern

TABLE 2

Species of fungi at various depths, soluble salts, and moisture content of soils

SOIL NUMBER	DEPTH OF SAMPLE	TOTAL SOLUBLE SALTS	MOISTURE	NAME OF ORGANISM
	inches	*p.p.m.*	*per cent*	
1	0–7	5,000	4.5	*Penicillium expansum* (Link) Thom, *Cephalosporium* sp., *Trichoderma lignorum* (Tode) Harz.
2	8–20	8,000	4.9	*Penicillium expansum* (Link) Thom, *Penicillium intricatum* Thom, *Stachybotrys cylindrospora* Jensen
3	0–7	28,000	5.5	*Penicillium expansum* (Link) Thom, *Macrosporium* sp.
4	8–20	12,000	3.9	*Penicillium expansum* (Link) Thom, *Cephalosporium* sp.
38	0–7	636	5.7	*Fusarium* sp., *Rhizopus nigricans* Ehrenb.
39	0–7	1,730	4.7	*Fusarium* sp. *Trichoderma lignorum* (Tode) Harz.
40	0–7	3,575	2.5	*Pencillium expansum* (Link) Thom, *Cephalosporium* sp.
41	0–7	1,860	3.2	*Penicillium expansum* (Link) Thom, *Trichoderma lignorum* (Tode) Harz, *Rhizopus niggricans* Ehrenb.
50	0–7	3,690	5.1	*Trichoderma glaucum* Abbott, *Trichoderma lignorum* (Tode) Harz, *Penicillium* No. 50
120	8–20	......	4.6	*Fusarium* sp., *Rhizopus nigricans* Ehrenb., *Trichoderma lignorum* (Tode) Harz.
154	0–7	414	2.8	*Fusarium* sp.
82	8–20	1,030	2.9	*Pencillium* No. 67
166	0–7	518	3.5	*Penicillium expansum* (Link) Thom, *Penicillium chrysogenum* Thom, *Penicillium funiculosum* Thom, *Verticillium terrestre* (Link) Lindau, *Fusarium* sp.
178	12–18	410	1.8	*Rhizopus nigricans* Ehrenb.
173	0–7	1,380	2.6	*Penicillium expansum* (Link) Thom, *Penicillium roseum* Link, *Rhizopus nigricans* Ehrenb., *Trichoderma lignorum* (Tode) Harz.
181	12–18	515	2.9	*Penicillium expansum* (Link) Thom, *Penicillium* No. 67, *Fusarium* sp., *Macrosporium* sp.
213	0–7	......	1.4	*Penicillium chrysogenum* Thom *Rhizopus nigricans* Ehrenb.
218	8–12	75,888	2.3	*Penicillium expansum* (Link) Thom, *Penicillium lilacunum* Thom.
206	0–7	......	1.4	*Trichoderma lignorum* (Tode) Harz.
196	40–42	510	1.9	*Penicillium expansum* (Link) Thom, *Trichoderma lignorum* (Tode) Harz.
197	0–7	720	2.7	*Fusarium* sp., *Trichoderma lignorum* (Tode) Harz.
187	0–7	206	2.2	*Penicillium expansum* (Link) Thom, *Rhizopus nigricans* Ehrenb., *Trichoderma lignorum* (Tode) Harz.

TABLE 2—*Continued*

SOIL NUMBER	DEPTH OF SAMPLE	TOTAL SOLUBLE SALTS	MOISTURE	NAME OF ORGANISM
	inches	*p.p m.*	*per cent*	
296	8-20	......	2.8	*Hormodendrum pallidum* Oud., *Spicaria simplicissima* Oud., *Trichoderma lignorum* (Tode) Harz.
90	0–7	522	4.4	*Penicillium expansum* (Link) Thom, *Aspergillus niger* van Tiegh., *Rhizopus nigricans* Ehrenb., *Trichoderma lignorum* (Tode) Harz.
91	0–7	208	4.1	*Penicillium expansum* (Link) Thom, *Penicillium lilacinum* Thom, *Penicillium* No. 55, *Fusarium* sp.
94	0–7	204	2.2	*Penicillium expansum* (Link) Thom, *Aspergillus glaucus* Link, *Penicillium roseum* Link, *Rhizopus nigricans* Ehrenb., *Trichoderma lignorum* (Tode) Harz.
95	8–20	416	3.8	*Penicillium expansum* (Link) Thom, *Rhizopus nigricans* Ehrenb., *Penicillium* No. 67, *Penicillium duclauxi* Delacroix.

localities, but is less abundant in the colder soils of the northern states (7, 16). This has been found to be true also under Colorado conditions. It is interesting to note that in the few samples from Colorado which Waksman (16) studied he did not isolate any member of this genus.

Aspergillus niger van Tiegh.

This organism was isolated from the surface of an unproductive soil of high moisture content.

Cephalosporium sp.

This form was isolated from the surface and the subsurface of productive and unproductive soils. Only a few colonies appeared on the medium from each isolation. Waksman (16) has reported the isolation of a member of this genus from this state.

Fusarium sp.

Eight soil samples representative of widely different conditions contained species of *Fusarium*. This was the only member of the Tuberculariaceae isolated. The amount of total soluble salts apparently did not limit the presence of this fungus. The fungus was found in the dry land section of the state and in the irrigated sections, in both productive and unproductive soils.

Hormodendrum pallidum Oud.

This fungus was one of the rare inhabitants of the soils. *Hormodendrum pallidum* was isolated from the subsurface of an unproductive stiff, yellow clay upon which crops have always made poor growth.

Macrosporium sp.

A species of *Macrosporium* was isolated from the surface of an unproductve soil in southern Colorado. This soil was exceptionally high in total soluble salts. It was also found in the subsurface of a cultivated soil from the dryland area which was very low in soluble salts.

Penicillium chrysogenum Thom.

This fungus was isolated from the surface of a non-irrigated, virgin soil and also from the surface of a virgin, brown silt loam in the irrigated district. Waksman (16) isolated *Penicillium chrysogenum* from a 10-year-old alfalfa field located near Fort Collins, Colorado.

Penicillium duclauxi Delacroix.

This fungus was isolated only once and then from the subsurface of a soil that contained very little mositure. The soil was a productive fine loam.

Penicillium expansum (Link) Thom.

This is a common and widely distributed species. It was isolated from 60 per cent of the soils examined. The species was very numerous as deep as 42 inches. It is of interest to note that the platings from a soil high in total soluble salts contained more colonies of *Penicillium expansum* than appeared on plates from any other soil examined. It was present in large numbers in productive and unproductive soils.

Penicillium funiculosum Thom.

This was one of the less prevalent species and was found associated with *Penicillium chrysogenum* in a virgin soil.

Penicillium intricatum Thom.

This was one of the rarer fungi of the soils examined. It was isolated from the subsurface of a productive soil which was high in total soluble salts.

Penicillium lilacinum Thom.

This was an uncommon species. It was isolated from an unproductive soil and from a virgin soil which was very high in total soluble salts.

Penicillium roseum Link

Penicillium roseum was isolated from two productive fields, one in the irrigated section and one in the dryland area of the state.

Penicillium No. 50.

Colonies irregular, non-zonate, white when young, later becoming dark brown with white margin; reverse red to brown. Growth rapid on bean agar and suppressed on gelatin. Does not liquify gelatin.

This form was isolated from a black clay which produces poor crops of corn and only fair yields of wheat. This soil was high in total soluble salts.

Penicillium No. 55.

Colonies round, zonate, white with a gray center; reverse yellow, growth slow, considerably suppressed on gelatin and not a spreader. Liquifies gelatin slowly.

One isolation of this form was made from a dark brown, silty clay located in a low area. The sample was from the subsurface soil.

Penicillium No. 67.

Colonies irregular, non-zonate, white when young, later becoming dark gray; reverse dark red. Growth rapid, and liquifies gelatin slowly.

This form was isolated from two productive soils in the irrigated section and also from a cultivated soil in the non-irrigated section of the state.

Rhizopus nigricans Ehrenb.

This form was isolated from 10 of the 27 soils examined and was abundant when present

in the soil regardless of soil type, depth, or relative productive capacity. It was found in the surface and subsurface of widely different soils. This fungus was not found in virgin soils.

Spicaria simplicissima Oud.

This fungus was isolated from the subsurface of an unproductive, yellow clay.

Stachybotrys cylindrospora Jensen.

This organism was isolated from the subsurface of a productive soil which was high in total soluble salts. It was found in only one soil.

Trichoderma glaucum Abbott

Only one soil examined contained this organism. It was isolated from the surface sample of an unproductive black clay.

Trichoderma lignorum (Tode) Harz

Next to species of Penicillia, *Trichoderma lignorum* was the most prevalent fungus in the soils examined. This fungus was found in greatest numbers in the surface and only occasionally at lower depths.

Verticillium terrestre (Link) Lindau.

This species was not common in the soil examined. It was isolated from a grayish brown, sandy, virgin soil in the non-irrigated region.

SUMMARY

The dominant type of fungi in Colorado soils seems to be species of Penicillia, whereas species of Aspergilli occur only occasionally. The three dominant groups of fungi in order of total numbers and in variety of species are Penicillia, Trichodermae, and Aspergilli. The rarer forms are species of *Cephalosporium*, *Verticillium*, *Spicaria*, *Hormodendrum*, *Macrosporium*, and *Stachybotrys*.

From the 27 soils studied it appears that soils low in moisture apparently favor the growth of *Rhizopus nigricans* and *Trichoderma lignorum*. Moisture did not seem to limit the presence of *Penicillium expansum*. Moisture content, which varied in the samples taken from 1.9 per cent to 5.5 per cent, apparently had no specific effect on the prevalence of other species.

The number of species of fungi isolated was considerably less in soils containing high quantities of soluble salts than in those of low salt content. Greater numbers of Penicillia were found in soils of high salt content than of any other fungus. *Penicillium expansum* and *P. lilacinum* were abundant under these conditions. Species of *Macrosporium* and *Cephalosporium* were also found in soils high in salts. *Trichoderma lignorum* and *Rhizopus nigricans* were abundant only in soils of low salt content. *Penicillium expansum*, *P. roseum*, *P. lilacinum*, *P.* No. 55, and *Fusarium* sp., were found in small numbers under low salt conditions.

Rhizopus nigricans and *Penicillium expansum* were common to both productive and unproductive soils, but were more abundant in the latter. *Trichoderma lignorum* was present only in the surface of these two soils. Greater

numbers of species of Fusaria were isolated from the productive than from the unproductive soils. *Penicillium glaucum*, *P. roseum* and *Cephalosporium* sp. were found only in productive soils, whereas *Macrosporium* sp. was isolated only in the unproductive soils. *Penicillium expansum* was isolated from 5 of the 8 samples of productive soils and also from 6 of the 9 samples of unproductive soils.

The number of species found decreased with depth. Only two species were isolated at 42 inches. *Trichoderma lignorum* and *Penicillium expansum* were present at all depths examined. *Aspergillus niger* was abundant only in the surface when present. *Fusarium* sp. was present in both the surface and subsurface of the soils examined. *Spicaria simplicissima* and *Hormodendrum pallidum* were isolated only from the subsurface. *Penicillium roseum* and *Penicillium* No. 50 were found in the surface, whereas *P. duclauxi*, *P.* No. 67, *P. lilacinum*, and *P.* No. 55 were present only in the subsurface.

REFERENCES

(1) ABBOTT, E. V. 1926 Taxonomic studies on soil fungi. *Iowa State Col. Jour. Sci.* 1: 15–36.

(2) BROWN, P. E. 1917 Importance of mold action in soils. *Science* (n. s.) 46: 171–175.

(3) DALE, ELIZABETH 1912 On the fungi of the soil: I. *Ann. Mycol.* 10: 452–477.

(4) DALE, ELIZABETH 1914 On the fungi of the soil: II. *Ann. Mycol.* 12: 33–62.

(5) GILMAN, J. C., AND ABBOTT, E. V. 1927 A summary of the soil fungi. *Iowa State Col. Jour. Sci.* 1: 225–343.

(6) GODDARD, H. M. 1913 Can fungi living in agricultural soil assimilate free nitrogen? *Bot. Gaz.* 56: 249–305.

(7) JENSEN, C. N. 1912 Fungous flora of the soil. *N. Y. (Cornell) Agr. Exp. Sta. Bul.* 315: 414–501.

(8) PAINE, F. S. 1927 Studies of the fungous flora of virgin soils. *Mycologia* 19: 248–267.

(9) RATHBUN, ANNIE E. 1918 The fungous flora of pine seed beds: I. *Phytopath.* 8: 469–483.

(10) RUSSELL, E. J., ET AL. 1923 The Microörganisms of the Soil. New York and London.

(11) TAYLOR, MINNIE W. 1917 Preliminary report on the vertical distribution of Fusarium in soil. *Phytopath.* 7: 374–378.

(12) THOM, C. 1910 Cultural studies of species of *Penicillium*. *U. S. Dept. Agr. Bur. Anim. Indus. Bul.* 118: 1–109.

(13) THOM, C., AND CHURCH, M. B. 1926. The Aspergilli. Baltimore.

(14) WAKSMAN, S. A. 1916 Soil fungi and their activities. *Soil Sci.* 2: 103–156.

(15) WAKSMAN, S. A. 1916. Do fungi live and produce mycelium in the soil? *Science* (n. s) 44: 320–322.

(16) WAKSMAN, S. A. 1917. Is there any fungus flora of the soil? *Soil Sci.* 3: 565–589.

(17) WAKSMAN, S. A. 1918 The importance of mold action in the soil. *Soil Sci.* 6: 137–155.

(18) WAKSMAN, S. A. 1922 A method for counting the number of fungi in the soil. *Jour. Bact.* 7: 339–441.

(19) WERKENTHIN, F. C. 1916 Fungous flora of Texas soils. *Phytopath.* 6: 241–253.

STUDIES WITH SULFUR FOR IMPROVING PERMEABILITY OF ALKALI SOIL

JOSEPH D. HAYNES[1]

Oregon State Agricultural College

Received for publication March 3, 1928

The reclamation of "black alkali" soil is a complicated problem because of the tendency to "freezing up" after a short period of leaching. According to Breazeale and Burgess (1) this is due to the hydrolysis of the sodium compounds in the ultra clay complex, which brings about this dispersion. Water disappears slowly into such land and, after it has passed from the surface, the deflocculated soil is hard and is unfavorable for crop production.

The object of the study reported herein was to learn the rate of percolation as affected by chemical treatment, wetting and drying, total salts removed, and change in hydrogen-ion concentration with exchange of calcium for sodium on the ultra clay complex.

METHOD

Malheur clay loam was employed in this study, 25-pound lots being used in each jar. The method used for determining the replaceable bases in alkali soil was that of Burgess and Breazeale (2), percolation tests being made over three periods of time, between which the soil was thoroughly dried. The first trial was for 252 hours, the second for 396 hours, and the third for 540 hours. Percolate from each jar was measured each 38 hours. At the end of each trial, the total amount of salts removed was determined by analysis of an aliquot part of the percolate. At the close of each trial, hydrogen-ion concentration determinations were made with a hydrogen electrode. At the beginning of each trial, the soil was thoroughly mixed to avoid channeling.

Nineteen jars of soil treated with sulfur, lime, and manure at different rates or in different combinations were used for this experiment. The first twelve jars were filled with Malheur clay loam (used by Young[2]), and the last seven jars were of the same type of soil, but having less alkali than the former.

[1] This investigation was made possible through the courtesy of the Western Sulphur Company of San Francisco, California, which has financed a fellowship in the soils department of Oregon State Agricultural College for the study of sulfur in relation to soil fertility.

[2] Young, V. D. (1925) Improvement in percolation of water through soils having a high clay content and restricted drainage. Master Thesis, Unpublished, table 2, p. 27. Ore. Agr. Col.

EFFECT OF SOIL TREATMENTS ON RATE OF PERCOLATION

The data from check jar 1 (table 1) show that leaching alternated with drying removed appreciable quantities of salts, with some decrease in alkalinity. Alternate drying and leaching appear to have some advantage in the reclamation of alkali land.

TABLE 1

Rate of percolation as affected by different soil treatments. Total loss and reaction change for a period of 1188 hours

JAR		PERCOLATION AT THE START AND CLOSE OF 396-HOUR TRIAL		TOTAL VOLUME WATER	TOTAL SALTS	REACTION	
		Start cc per 36 hours	Close cc. per 36 hours	cc.	gm.	Start pH	Close pH
	Treatments, series 1						
1	Check	330	180	13,588	46 2669	10.8	9.2
2	20 tons manure	350	140	10,330	65 3636	10.5	9.0
3	6 tons lime, 20 tons manure	450	230	20,248	45.5984	10.5	9.1
4	6 tons lime	480	220	13,590	38.6448	10.2	9.4
5	2000 pounds sulfur	580	220	13,070	60.6222	10.2	8.8
6	1200 pounds sulfur	590	290	17,470	46.6966	10.5	9.0
7	10 tons gypsum, 2000 B.G.S.*	510	210	14,585	52 0763	9.8	9.1
8	1200 pounds gypsum	340	140	10,170	32.7278	10.5	9.1
9	1200 pounds sulfur, 20 tons manure	640	240	12,480	30.1181	10.5	9.1
10	20 tons green manure	390	190	12,980	53.9357	9.8	9.0
11	4000 pounds alum	440	190	11,250	27.8136	10.2	9.1
12	Saturated solution gypsum	570	190	11,930	33.1435	10.7	9.2
	Treatments, series 2						
13	Black gas sulfur 2000 pounds	220	110	7,180	37.7331	9.5	8.7
14	Black gas sulfur 3000 pounds	480	140	11,785	62.7898	9.5	8.5
15	Black gas sulfur 4000 pounds	420	100	15,375	53.0267	9.5	8.3
16	Sulfur 3000 pounds	320	100	8,610	60.2808	9.5	8.4
17	Bac-sul sulfur 3000 pounds	320	100	8,070	57.1715	9.5	8.6
18	Gasco 3000 pounds	260	70	6,540	32.5421	9.5	8.8
19	Check	270	70	4,520	12.6401	9.5	9.0

* B.G.S. = Black gas sulfur

Sulfur at the rate of 2000 pounds an acre removed a large amount of total salts and the alkalinity decreased from pH 10.2 to 8.8, as shown by jar 5.

Series 2, jar 15 treated with 4000 pounds of sulfur to the acre allowed a rapid percolation, compared to check jar 19 of the same series. The average hourly

rate of percolation for the three trials from jar 15 was 12.9 cc., and for the check jar 19, 3.8 cc. The alkalinity decreased in jar 15 from pH 9.5 to 8.3; and in check jar 19, the pH was lowered from 9.5 to 9.0.

Manure, green manure, sulfur with gypsum, and sulfur alone all decreased the hydrogen-ion concentration to some extent, yet the most effective decrease resulted from sulfur treatments.

Lime and manure (jar 3) tend to keep the soil open, yet the total salt is not so rapidly removed when compared to the sulfur-treated jars. This probably is because the sulfur forms sulfuric acid, which changes active alkali to a neutral salt, which is leached from the soil.

TABLE 2

Exchangeable bases as affected by treatments and leaching

Malheur clay loam

JAR			pH
	Treatments, series 1		
1	Check	Replaceable Ca 0.1080 Replaceable Na 0.3588	9.2
7	10 tons gypsum plus 2000 B.G.S.	Replaceable Ca 0.1620 Replaceable Na 0.2737	9.1
9	1200 pounds sulfur 20 tons green manure	Replaceable Ca 0.1260 Replaceable Na 0.3160	9.1
	Treatments, series 2		
14	Sulfur *B.G.S. 3000 pounds	Replaceable Ca 0.2790 Replaceable Na 0.1506	8.5
15	Sulfur B.G.S. 4000 pounds	Replaceable Ca 0.2960 Replaceable Na 0.1006	8.3
19	Check	Replaceable Ca 0.1800 Replaceable Na 0.2530	9.0

* B.G.S. = black gas sulfur.

As the total concentration is reduced by leaching, the soil tends to become more impermeable to water, especially that in check jars. Percolation in sulfur-treated soil decreased least with time.

An exchange of sodium for calcium on the ultra clay complex is found to take place with the different treatments. Table 2 shows the replacement of sodium ion by the calcium ion on the ultra clay complex caused by the use of sulfur and leaching. It appears that, between pH 9.0 and 8.3, the calcium becomes reactive and rapidly displaces the sodium. This soil at a pH above 8.5 tends to have a high concentration of sodium on the complex.

The ratio of sodium to calcium on the complex changes with the salt concentration of the soil solution. Some sodium will be removed from the complex when the concentration of salts in the soil solution is reduced. It is not necessary to neutralize the soil solution before exchangeable sodium will be replaced by calcium. A change in concentration will cause a base exchange on the clay complex.

CONCLUSIONS

1. Alternate wetting and drying increased the permeability of a dispersed black alkali soil.
2. Sulfur treatments increased the rate of percolation from alkali soil and decreased the total alkalinity. Sulfur-treated soil remains more open and permeable in extended percolation trials than non-treated soil.
3. The most effective decrease in pH resulted from sulfur treatments.
4. Lime and manure treatments aid in maintaining permeability during leaching.
5. Rate of percolation in treated and untreated soils decreased with time.
6. Sulfur treatments of soil subjected to leaching cause calcium to become reactive and to displace the sodium on the ultra clay complex. For the soil employed, a pH above 8.5 has a high concentration of sodium on the complex. Base exchange is a continuous process and is affected by the concentration of salts in the soil solution.

REFERENCES

(1) Breazeale, J. F., and Burgess, P. S. 1926 The reaction between calcium sulfate and sodium carbonate, and its relation to the reclamation of black alkali land. Univ. Ariz. Tech. Bul. 6.
(2) Burgess, P.S., and Breazeale, J. F. 1926 Methods for determining the replaceable bases of soils, either in the presence or absence of alkali salts. Univ. Ariz. Tech. Bul. 9.

THE RATE OF AVAILABILITY OF VARIOUS FORMS OF SULFUR FERTILIZERS

JOSEPH D. HAYNES[1]

Oregon State Agricultural College

Received for publication March 3, 1928

The use of sulfur as a fertilizer in arid regions is attracting much attention. Sulfur is coming to be extensively used as a fertilizer for alfalfa and other similar crops on normal soils, especially in the basaltic soil region of northwestern United States. Sulfur also offers a means of reclaiming "black alkali" land that has been provided with deep drainage and copious irrigation.

Factors determining the application of this method of soil improvement hinge on ability of various arid soils studied to convert the relatively insoluble sulfur to active or usable sulfate form.

The object of this study has been to determine the sulfate-supplying power of different materials with different soils. Soils employed in the work include a "black alkali" soil, Malheur clay loam, pH 9.5; Umatilla medium sand, a soil giving little response to sulfur fertilizer; and a neutral soil, Deschutes sandy loam, that gives good response to sulfur when used as a fertilizer for legumes.

METHODS

An experiment was planned to determine: first, how rapidly the sulfur is oxidized in these different soils; second, the relative value of the several different forms of sulfur available for this purpose; and third, the effects of sulfur on chemical, physical, and biological changes in soil.

Sulfur fertilizers used (table 1) were:

"Black Gas Sulfur" a new commercial material which is a by-product of gas plants. It is colloidal, hydrophilic, and runs about 89 to 95 per cent sulfur.

"Bac-sul" is a powdered sulfur containing *Thiobacillus thiooxidans* an organism isolated by Lipman and associates and later used to activate sulfur fertilizers.

"Black Gas Sulfur"—melted and ground.

"Gasco By-product," a by-product from Portland Gas and Coke Company, containing about 43 per cent sulfur.

Sand Sulfur, a crushed crude lump sulfur that is larger than 10 mesh.

---

[1] The author takes this opportunity to thank Dr. W. L. Powers for council during the execution of this work and to Dr. R. E. Stephenson and Dr. W. V. Halverson for technical suggestions and advice.

This investigation was made possible through the courtesy of the Western Sulphur Company of San Francisco, California, which has financed a fellowship in the soils department of Oregon Agricultural College for the study of sulfur.

Untreated soils of each type were included.

Air-dry soil was weighed out in 2-pound amounts, placed in quart mason jars, and mixed with sulfur in different rates and forms, water being added until an optimum moisture condition was reached. This was maintained during the experiment, treatments as shown in table 2. Sulfate determinations were made periodically from 1:5 water extract, and precipitation with a solution of barium chloride was followed by gravimetric determinations. Heavy applications of sulfur were used in order to obtain differences that would be significant.

A medium for determining the number of microörganism in the soil was made according to Fred and Waksman (2).

The hydrogen-ion concentration of the soil was determined electrometrically by the use of the hydrogen electrode.

TABLE 1

Rate of oxidation of different forms of sulfur on Deschutes Sandy Loam

TREATMENT (1000 POUNDS PER ACRE)	3 WEEKS, SO_4	PERIOD OF INCUBATION				S OXIDIZED IN 9 WEEKS
		6 weeks		9 weeks		
		SO_4	pH	SO_4	pH	
	gm.	*gm.*		*gm.*		*per cent*
Check	0.0339	0.0499	7.2	0.0550	7.2	0
Black gas sulfur melted and ground	0 0740	0.1207	6.8	0.1544	6.4	66.6
Gasco by-product (43 per cent S)	0 0575	0.0797	7.1	0.0820	7.1	41.8
Black gas sulfur (colloidal)	0.0987	0.1295	6.3	0.1290	6.4	49.3
Bac-sul	0.0986	0.1143	6.5	0.1169	6.4	41.2
Sand sulfur	0.0330	0.0611	7.1	0.0964	6.8	27.6

EXPERIMENT 1

Data presented in table 1 indicate that black gas sulfur oxidizes at a comparatively rapid rate. The Gasco by-product oxidizes at a rate comparable to other commercial sulfur. Sand sulfur oxidizes slowly because of the small surface area exposed.

EXPERIMENT 2

The amounts of sulfates formed after 2, 4, 8, and 16 weeks are represented in table 2. Black gas sulfur oxidized at approximately the same rate as the inoculated sulfur, except with the alkaline, Malheur clay loam. The inoculated sulfur for the first 8 weeks oxidized more rapidly than the black gas sulfur, after which time the two yielded similar amounts of sulfates.

This work indicates that sulfur oxidizes rapidly under alkaline conditions, and that the high concentration of salts does not prevent sulfur oxidation. This is in accord with findings of Kelley and Thomas (3) and Samuels (6). The high carbonate content appears to accelerate oxidation.

From this work it appears that after 2 months, sulfur on Malheur clay loam would oxidize sufficiently so that leaching could take place. The tendency is for rapid oxidation the first 8 weeks and then the process slows up, probably

TABLE 2

Oxidation studies on three arid soils

JAR		2 WEEKS		4 WEEKS		8 WEEKS		16 WEEKS		S OXIDIZED
		SO_4	pH	SO_4	pH	SO_4	pH	SO_4	pH	
		gm.		*gm.*		*gm.*		*gm.*		*per cent*
	Malheur clay loam									
1	Check	0 0351	9.5	0.0738	9.4	0.0781	9.5	0 0879	9.5	0
2	1 ton B.G.S.*	0.1176	8.2	0.2982	8.1	0.3109	8.1	0.3482	7.8	86.0
3	2 tons B.G.S.	0.1307	7.7	0.3966	7 7	......	7.5	0.5384	6.5	74.2
4	4 tons B.G.S.	0.3680	6.5	0.4112	6.4	......	6.3	0.5927	5.1	41.9
5	8 tons B.G.S.	0.4310	6.3	......	6.2	0.5675	5.9	0.6827	3.8	24.6
6	1 ton inoculated	0.1922	8.2	0.3135	8.1	0.3206	7.8	0.3520	7.5	87.6
7	2 tons inoculated	0.2889	8.2	0.4103	7.9	0.3940	7.5	0.6107	5.4	86.5
8	4 tons inoculated	0.4606	7.7	......	6.8	0.4914	6.5	0 6970	4.3	50.0
9	8 tons inoculated	0.5075	6.8	0.4903	6.2	0.7879	5.6	0.7114	3 9	25.4
	Umatilla medium sand									
10	Check	0.0000	7.9	0 0039	7.9	0.0084	7.9	0.0181	7.9	0
11	1 ton B.G.S.	0.0220	6.2	0.0738	4.8	0.1883	4.4	0.2304	3.8	70.1
12	2 tons B.G.S.	0.0777	5.2	0.1594	4.1	0.2890	3.9	0.3717	3.8	58.3
13	4 tons B.G.S.	0.1048	5.0	0.1761	4.1	0.2693	3.8	0.5339	3.0	43.7
14	8 tons B.G.S.	......	4.8	......	4.1	0.4036	3.7	0.4188	2.9	16.6
15	1 ton inoculated	0.0128	5.8	0.0831	4.8	0.1699	4.8	0.2210	4.3	70.7
16	2 tons inoculated	0.0139	5.8	0 0993	4.4	0.1891	4.4	0.3591	3.4	56.4
17	4 tons inoculated	0.0634	5.3	0.1527	4.1	0.3708	3.7	0.4165	3.2	33.2
18	8 tons inoculated	0.0651	5.3	0.1584	4.1	0.3605	3.7	0.4983	2.8	19.9
	Deschutes sandy loam									
19	Check	0.0445	7.2	0.0557	7.2	0.0561	7.2	0.0672	7.1	0
20	1 ton B.G.S.	0.1402	6.1	0.2307	5.5	0.2386	5.4	0.2861	5.3	72.8
21	2 tons B.G.S.	0.1948	5.2	0.3460	4.8	0.3429	4.8	0.4124	4.7	57.4
22	4 tons B.G.S.	0.2326	5.2	0.3168	4.8	0.4315	4.4	0.4907	3.7	34.9
23	8 tons B.G.S.	0.2468	5.2	0.3570	4.5	0.5758	4.2	0.5200	2.8	18.6
24	1 ton inoculated	0.1471	5.8	0.2419	5.4	0.2651	5.3	0.2957	5.4	76.1
25	2 tons inoculated	0.2478	5.0	0.3284	4.9	0.4052	4.5	0.4063	4.4	56.5
26	4 tons inoculated	0.2803	5.0	0.3936	4.8	0.5371	4.2	0.4415	3.7	31.1
27	8 tons inoculated	0.2824	5.1	0.4018	4.8	0.5894	4.1	0.6978	3.1	26.0

* B.G.S. = black gas sulfur.

because of accumulated acidity. This was particularly noticeable with the heavy applications. Bacterial counts verified this, showing fewer bacteria with the extremely heavy application; however, with the black alkali soil,

Malheur clay loam, applications of sulfur in most instances increased the microflora of both bacteria and molds.

TABLE 3

Microörganisms per gram air-dry soil

JARS	TREATMENTS	MOLDS (Millions 000 omitted)	BACTERIA	pH
Malheur clay loam				
1	Check	29,500	1,620	9.5
2	1 ton B.G.S.*	29,500	2,520	7.8
3	2 tons B.G.S.	51,400	2,320	6.5
4	4 tons B.G.S.	95,000	2,050	5.1
5	8 tons B.G.S.	34,000	1,450	3.8
6	1 ton inoculated	43,500	2,060	7.5
7	2 tons inoculated	44,900	1,830	5.4
8	4 tons inoculated	59,000	1,790	4.3
9	8 tons inoculated	26,000	1,920	3 9
Umatilla medium sand				
10	Check	27,400	2,870	7.9
11	1 ton B.G.S.	34,600	1,340	3.8
12	2 tons B.G.S.	29,000	383	3.8
13	4 tons B.G.S.	62,000	81.5	3.0
14	8 tons B.G.S.	94,000	11	2.9
15	1 ton inoculated	41,300	1,640	4 3
16	2 tons inoculated	33,300	394	3.4
17	4 tons inoculated	94,000	23 3	3 2
18	8 tons inoculated	91,000	11.6	2.8
Deschutes sandy loam				
19	Check	61,200	1,570	7.1
20	1 ton B.G.S.	137,000	2,250	5.3
21	2 tons B.G.S	124,000	1,870	4.7
22	4 tons B.G.S.	62,800	651	3.7
23	8 tons B.G.S.	251,000	77	2.8
24	1 ton inoculated	187,000	1,850	5.4
25	2 tons inoculated	128,000	1,540	4.4
26	4 tons inoculated	52,500	59	3.7
27	8 tons inoculated	55,000	10	3.1

* B.G.S. = black gas sulfur.

Flocculation with sulfur

Flocculation effect on certain soils, namely, Malheur clay loam, Umatilla medium sand, and Deschutes sandy loam are shown in plate 1. These photographs were taken at the end of a 16-week incubation period. Treatments are recorded in table 2.

Soils treated with sulfur were flocculated as represented in plate 1, figure 2. Checks in all cases remained dark, the treated tubes clearing up. Heavy applications of sulfur caused flocculation more rapidly than light applications.

With alkali soils, flocculation begins as neutrality is approached, definite flocculation having started at pH 7.5. This flocculation according to Comber (1) is in part indirect and is due to bringing into solution some other material which flocculates the soil. The material that is brought into solution in the greatest quantity from the application of sulfur, according to Powers (5) and Larson (4), is calcium. It appears that flocculation from sulfur is due to bringing into solution calcium and possibly some other ions that would tend to flocculate, along with the neutralizing effects from the sulfur.

Sulfofying powers of arid soils vary to some extent, as shown in table 2. However, all these soils appear to possess sufficient sulfofying power to supply sulfates for growing crops. The alkaline Malheur clay loam oxidized sulfur rapidly. The carbonates appear to have accelerated this process.

Under alkaline conditions, inoculated sulfur oxidizes more rapidly in the initial period than does the non-inoculated sulfur for the first two months.

The microflora of the soil changes with the application of sulfur. Under alkaline conditions the sulfur applications increase the bacterial and the mold counts (table 3).

Hydrogen-ion concentration changes according to the amount of sulfur added, the carbonates present, and the type of soil. One ton of sulfur was required to change the pH of alkali soil from 9.5 to 7.8 whereas the 1 ton changed Umatilla medium sand from pH 7.9 to 3.8.

CONCLUSIONS

1. Black gas sulfur becomes available at approximately the same rate as inoculated sulfur, except on alkali soil. During the first eight weeks the inoculated sulfur yielded sulfates more rapidly than did the non-inoculated sulfur.

2. Under alkaline conditions sulfur appears to have increased the microflora of the soil, probably because of neutralizing alkali present, which produces a favorable flora for soil organisms.

3. Sulfur produces a decided, flocculating effect on alkali soils. Soils treated with 4000 pounds of sulfur are flocculated rapidly, whereas non-treated soils remain deflocculated. Flocculation starts as neutrality is approached.

4. Hydrogen-ion concentration changes with amount of sulfur added to the soil, type of soil, and carbonates present, for it takes larger quantities of sulfur to change the reaction of alkali soil than of neutral soil.

REFERENCES

(1) Comber, N. M. 1921 The flocculation of soils. *Jour. Agr. Sci.* 12: 451.

(2) Fred, E. B., and Waksman, S. A. 1922 A tentative outline of the plate method for determining the number of microörganisms in the soil. *Soil Sci.* 14: 27-28.

(3) Kelley, W. P., and Thomas, E. E. 1923 The removal of sodium carbonate from soils. Univ. Calif. Tech. Paper 1.

(4) Larson, H. W. E. 1928 The relation of calcium in requirements of alfalfa to the calcium concentration of the soil. *Soil Sci.* 25: 399–408.

(5) Powers, W. L. 1927 Studies with sulfur in relation to the soil solution. *Univ. Calif. Pubs. Agr. Sci.* 5: 119–166.

(6) Samuels, C. D. 1927 The oxidation of sulfur in alkali soils and its effect on the replaceable bases. *Univ. Calif. Hilgardia*, v. 3, no. 1.

PLATE 1

Fig. 1. Flocculation of Alkaline Soil with Sulfur

Treatments (left to right)—check, 1 ton, 2 tons, 4 tons, 8 tons, after sixteen weeks' incubation.

Fig. 2. Flocculation of Slightly Alkaline Soil with Sulfur

Treatments (left to right)—check, 1 ton, 2 tons, 4 tons, 8 tons, after sixteen weeks' incubation.

Fig. 3. Flocculation of Neutral Soil with Inoculated Sulfur

Treatments (left to right)—check, 1 ton, 2 tons, 4 tons, 8 tons, after sixteen weeks' incubation.

FIG. 1

FIG. 2

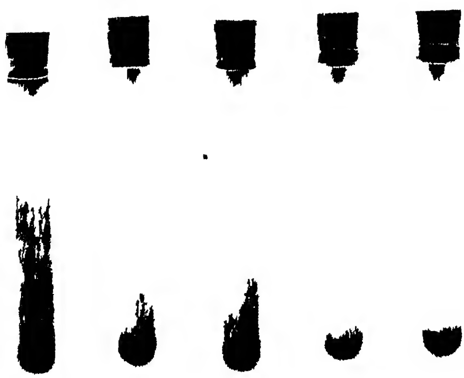


FIG. 3

A SIMPLE SPEED CONTROLLER, ESPECIALLY ADAPTED TO THE MOISTURE-EQUIVALENT CENTRIFUGE

F. J. VEIHMEYER AND C. V. GIVAN[1]

California Agricultural Experiment Station

Received for publication March 5, 1928

It is often necessary to reduce in magnitude the variations in the speed of rotation of an electric motor which is operated under varying loads and with fluctuations in the line voltage or frequency. A simple speed controller has been constructed at the University of California to meet these needs. This device was designed for the particular purpose of regulating the speed of a centrifuge used in making moisture-equivalent determinations of soils after a small spring-centrifugal governor control, attached to the motor shaft and furnished by the manufacturer, proved to be unreliable. A similar spring-governor control attached to a direct-current motor has been described by Briggs and McLane (1). Although particularly designed for the specific purpose indicated, the new device may be used to control the speed of other apparatus driven by an electric motor.

The essential details of the controller are shown in plate 1. The steel reed which is held in a standard, and which may be adjusted in length by means of regulating and clamp screws, is the principal feature of the device. The length of the reed is so adjusted that it has a natural frequency of vibration slightly higher than the frequency of rotation at which the motor is to be maintained. The reed is actuated by means of a magnetic field set up by a solenoid held in position over the reed. The solenoid may be moved in and out of the brass shell in which it is housed, by means of an adjusting screw, which may be clearly seen at the top of the shell in plate 1, figure 1. The solenoid shell is attached to an arm pivoted in the bifurcated end of the supporting pillar. The pivot is screwed through the ends of the pillar and by tightening the screw the solenoid shell may be fastened in place. A coarse adjustment of the distance between the end of the solenoid and the reed may be obtained with the adjusting screw, which extends through the supporting arm of the solenoid shell. The pillar may be turned so as to move the solenoid to one side when adjusting the reed. The position of the clamp which holds the reed may be adjusted. The manner of supporting the reed and the solenoid, and their means of adjustment, are shown in plate 1, figure 2.

The reed is made by straightening a section of the main spring of an ordinary

[1] Assistant professor of irrigation investigations and practice, and junior irrigation engineer, respectively.

pocket watch. The unsupported end of the reed is filed to a very slender tip about one-fourth of an inch long, and the tip is bent down so that it may pass through a small hole (about $\frac{1}{32}$ inch in diameter) in the cover of the mercury cup (pl. 1, fig. 2). This hole has a diameter just sufficient to give clearance to the tip of the reed. This slight clearance largely prevents the mercury from leaving the cup when the reed vibrates. An open mercury cup was tried but it was found that minute particles of mercury accumulated on the reed, thereby increasing the weight of the vibrating system and decreasing its vibration period. Although the arrangement shown in plate 1 greatly lessens this difficulty, it is necessary occasionally to brush off the end of the reed.

The mercury cup can be made of any non-magnetic material with which the mercury will not amalgamate. In the instrument illustrated, the cup is made of fibrous material, such as is used in the manufacture of timing gears of automobile engines. The level of the mercury in the cup is adjusted by turning the screw, shown in plate 1, figure 1, which projects into the cup.

The small spool solenoid which actuates the reed is similar to the type used on the ordinary telegraph sounder. In order to prevent wide variations in the maximum field strength established by this solenoid resulting from small resistance changes, a potential difference of 4 volts is maintained through it, which keeps the iron core well saturated. A small voltmeter and rheostat are inserted in the circuit, and as the batteries decrease in strength, resistance is cut out of the circuit.

The standard moisture-equivalent centrifuge is equipped with two slip rings and carbon brushes on the lower end of the motor shaft. A small piece of hard rubber was inserted into the lower slip ring so that the circuit which energizes the solenoid is interrupted for an instant as the brush passes over the rubber segment each time the motor revolves.

The relay[2] which closes the shunt around the line resistance is made from a telegraph sounder on which is mounted a sealed glass tube containing two contacts. This tube is filled with an inert gas to reduce sparking, and contains a drop of mercury, which slides away from one contact tip as the solenoid of the sounder is energized and the sounder bar depressed.

A diagram of the operating circuit is shown in figure 1. Each time the shaft of the motor revolves the circuit containing the solenoid M_1 is broken as the brush S_2 passes over the non-conducting segment of the slip ring Sr_2. Consequently, a pulsating magnetic field, which increases and decreases with each revolution of the motor, is established around the solenoid.

The normal resonance curves of the reed VR are shown in figure 2. The full line represents the resonance curve of the reed when it is actuated by a

[2] The relay is not an original feature of the apparatus. Anyone of the several types which may be purchased from instrument manufacturers will probably serve as well as the one described. The tube was made especially for the writers by the Federal Gauge Company of Chicago, Illinois. A contact made in an open cup of mercury when the sounder bar was depressed was tried at first but proved to be unsatisfactory.

pulsating field of normal intensity. When the intensity of the field is decreased the resultant resonance curve is as shown by the dotted line. The reed is tuned by adjusting its length until its natural vibration period, OX_3, is slightly greater than the speed OX, at which the motor is to be maintained. The desired speed must fall within the section containing the rapidly rising limb of the resonance curve.

As soon as the reed attains an amplitude of vibration OY, the tip of the reed makes contact with the surface of the mercury in the cup at K_1. A current flows through the circuit containing the solenoid M_2 which pulls

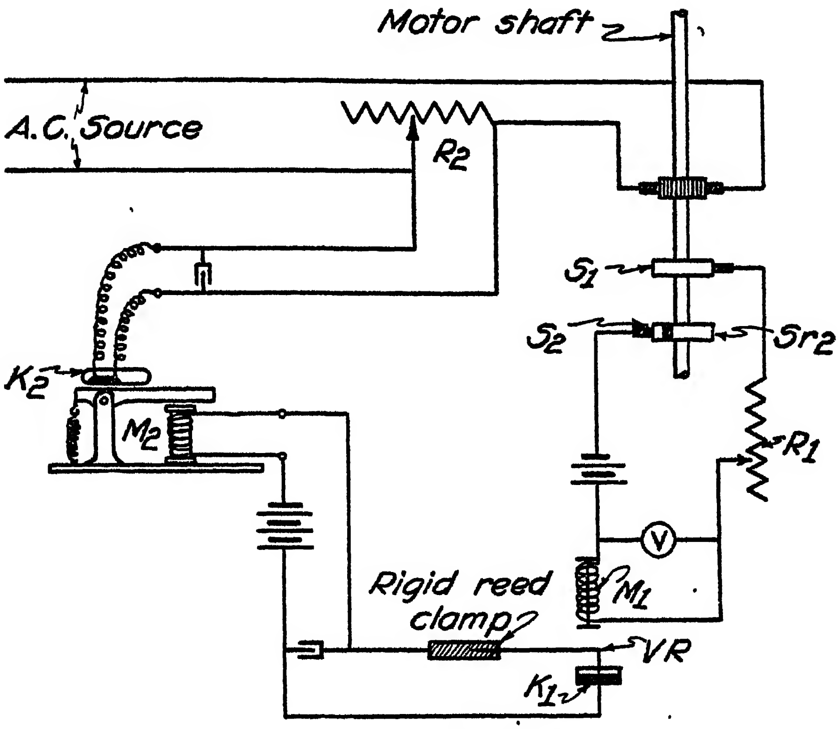


FIG. 1. THE OPERATING CIRCUIT OF THE SPEED CONTROLLER

down the telegraph sounder and breaks the shunt circuit at K_2 around the resistance R_2 in the line circuit. The vibrating reed merely acts as a switch that intermittently operates a relay which breaks a shunt circuit around line resistance whenever the motor speed reaches a certain magnitude. When operating, the speed controller breaks the circuit at approximately one-second intervals, although the time depends somewhat upon the amount of resistance inserted in the line and upon the line voltage. Condensers of about two microfarads capacity are connected across both contacts K_1 and K_2 in order to decrease sparking when each circuit is broken.

The controlled speed of the motor may be varied by changing the unsupported length of the reed, the distance between the mercury level and neutral position of the reed tip, and the strength of the pulsating magnetic field. Any large variation in controlled speed can be made only by changing the unsupported length of the reed. Referring again to figure 2, it can be seen that if the mercury level is lowered so that the vibrating reed must be displaced a distance OY_1 before it can make contact with the mercury, the operating speed of the machine is increased from OX to OX_1. If the strength of the magnetic field is weakened, the reed does not attain sufficient amplitude to

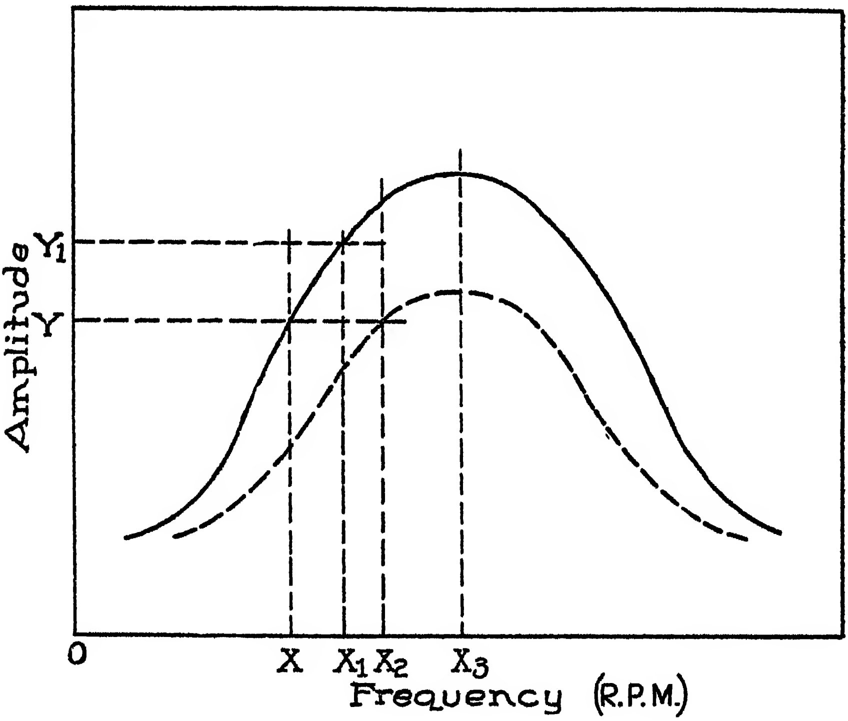


FIG. 2. NORMAL RESONANCE CURVES OF THE VIBRATING REED

make contact with the mercury until the motor attains the speed OX_2, the dotted line representing the resonance curve of the reed when actuated by the weakened field. The frequency curves shown in figure 2 are of the same type as result from the free vibration of a reed of the kind used on the speed controller. Little is known of the shape of the cruve after contact is made with the mercury, except that the peak is flattened considerably.

The centrifuge which is regulated by this device is maintained between limits, as recorded by a Hasler tachometer, of 2438 and 2443 r.p.m. The Hasler tachometer measures the actual number of revolutions over a 3-second

interval; consequently, speed variations for lesser intervals could not be determined. The centrifuge has been in use daily for periods up to several weeks without adjustment of the controller and the speed has not varied beyond the limits given above.

The speed-control mechanism as described above has superseded one in which steel reeds were excited by the direct vibration of the centrifuge itself.[3] This previous device proved to be unsatisfactory because varying degrees of unbalance of the centrifuge caused rather large variations in its speed. This was due to the variations in amplitude of vibration of the reeds and disturbance of the mercury level.

It is not claimed that the speed controller described herein, which uses a vibrating steel reed as the controlling element, is superior in the matter of speed regulation to some other controllers that have been reported in the literature. However, the device described above has proved to be much more satisfactory than the spring-centrifugal governor furnished with the centrifuge by the manufacturer, and, as far as the writers are aware, it is the simplest apparatus yet devised for the regulation of speeds within such narrow limits as indicated above. Three of the speed control devices for which very close regulation of speeds is claimed, and which involve some features which are similar to those of the controller described herein, will be briefly mentioned.

The apparatus developed by E. F. W. Alexanderson of the General Electric Company, uses a resonant electrical system instead of a resonant mechanical system as the controlling element. The use of a resonant electrical circuit complicates the controlling mechanism considerably, but when the closeness of its control was tested by comparison with a tuning fork it was found (3) that momentary variations in speed did not exceed 0.04 per cent, even though variations between a wider range occurred over longer intervals. The resonant electrical circuit is excited by a high frequency generator connected with the shaft of the machine whose speed is to be controlled. The natural frequency of the tuning circuit is adjusted by variable reactance and capacity, so that the desired speed of the machine is on the rising limb of the resonance curve, a curve similar to that in figure 2. This circuit is loosely coupled to a circuit containing a vacuum-tube rectifier and a part of one of the coils of a voltage regulator. When, for any reason, the speed rises, the current in the resonant circuit increases and thus operates the voltage regulator just as if there had been a rise in voltage.

In the Leeds and Northrup controller (2) a small rotary convertor or motor-generator set is controlled by an electrically driven tuning fork. The Wenner device (2) is an arrangement of a special rotating switch on the motor shaft and a contact controlled by an electrically driven tuning fork. As the motor speed rises a resistance in series with the field of a direct current motor is short-circuited until the speed decreases.

[3] Credit is due J. J. Cantor for the development of the instrumental details of this system while he was a student and laboratory assistant.

An electrically driven tuning fork is an essential feature of both aforementioned devices. Although these two controllers also make use of a vibrating mechanical system, there is this difference between them and the one described by the writers. In both the Leeds and Northrup and the Wenner controllers, the tuning fork is actuated continuously by a solenoid which is energized from a source not influenced by the speed of the motor under control.

The principal advantage of the vibrating reed controller developed by the writers is that it can be constructed by any competent laboratory mechanic at a low cost.[4]

REFERENCES

(1) Briggs, L. J., and McLane, J. W. 1910 Moisture equivalent determinations and their applications. *Proc. Amer. Soc. Agron.* 2: 138–147.

(2) Laws, F. A. 1917 Electrical Measurements. p. 431–433. New York.

(3) Whitehead, J. B., and Grondahl, L. O. 1920. Submarine detection in an alternating magnetic field. *Jour. Amer. Inst. Elect. Engin.* 39: 223-234, 381-395

---

[4] A patent for this device will be applied for by the University of California.

PLATE 1

Fig. 1. The speed controller, showing the essential parts of the apparatus.

Fig. 2. The speed controller with the solenoid swung to one side when adjusting the vibrating reed.

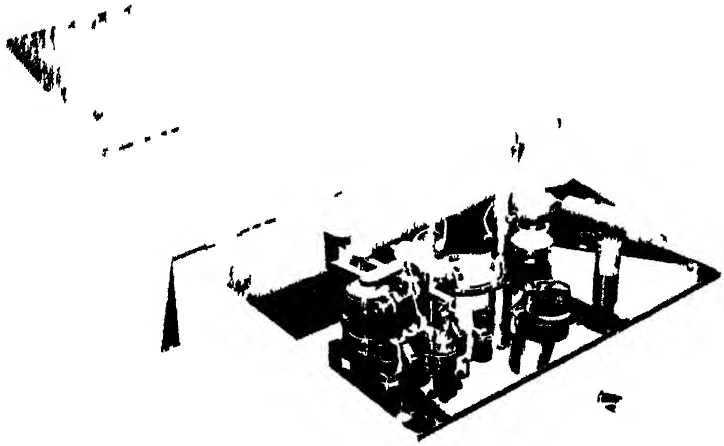


Fig 1

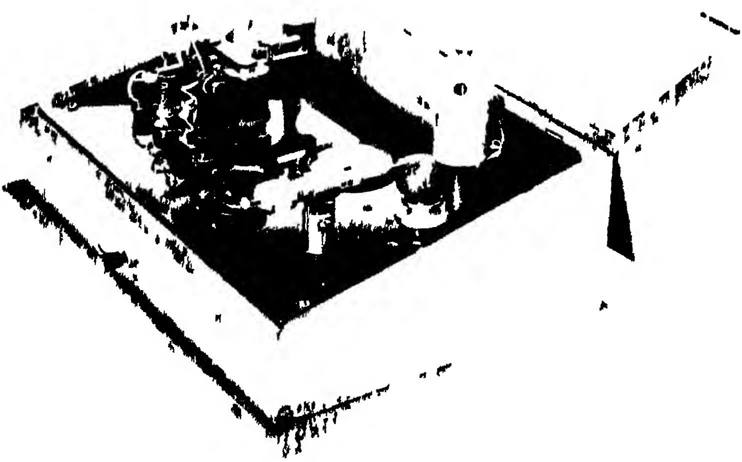


Fig 2

PHOSPHATE APPLICATIONS AND THEIR INFLUENCE ON CHERNOZEM: IV.[1] THE REVERSION OF P_2O_5 IN SOILS

M. A. EGOROV[2]

Kharkov Agricultural Experiment Station, U.S.S.R.

Received for publication February 16, 1928

A great deal of uncertainty still prevails as to the fate of phosphates applied to the soil. The changes that phosphates undergo in the soil have been studied either by the analysis of extracts, or by crop yields. Neither of these, however, is a reliable index.

In general, the transformation of phosphoric acid from super phosphate into some other form takes place as presented in the following equations:

$$Ca(H_2PO_4)_2\,(Ca') \rightarrow CaHPO_4\,(Ca'') \rightarrow Ca_3(PO_4)_2\,(Ca''')$$

There is a possibility of the formation of a still higher phosphate and all of this is known as reversion of phosphates. The direction of this process of reversion, the speed of its development, and the conditions responsible for it have been studied extensively and a voluminous literature is available. However, a great deal is still unknown or obscure.

In the studies reported elsewhere (1, 2, 4) these problems were analyzed and discussed. In reference to the speed of reversion it is well to recall the work of Stoklasa (8) who puts the time limit for the reversion of the phosphates as 50 to 60 days. The author's investigations (3) show that the process of reversion takes 24 days, and Shapiro (7) claims that it is completed in 10 days. Apparently the differences in the time periods for reversion are due to the character of the soil.

Elsewhere it has been shown by the author that the differences in the movement of the soil calcium are in a way responsible for the reversion. There is, however, sufficient proof that the iron in the soil is one of the factors contributing toward the reversion of the phosphates.

The residual value of the phosphates in terms of crop response after two, three, or even more years is closely related to the problems of reversion.

A very interesting point was brought out by Taranov (9). In 1918 pot experiments were started to test various sources of phosphates on wheat. The experiment was continued for four years. Table 1 gives the plan and the results of the tests. The data have been recorded in relative units by taking

[1] For other papers see references (1, 2, 4).

[2] Translated from the original Russian manuscript by Dr. J. S. Joffe, New Jersey Agricultural Experiment Station.

the sum total yield for the four years. The source of nitrogen and potash was KNO_3.

In the soils investigated by the author the reversion of phosphates was completed in 24 days. It would seem reasonable to expect that the phosphates of Na, K, Mg, Ca′, Ca″ should be transformed in the soil into the same form. The immediate and especially the residual effects should be the same irrespective of the form of phosphate applied. However, this was not the case. In the third year, after the phosphate application, the relative yields were as follows: Without phosphorus 100 per cent, with K-phosphates 205 per cent, with Na-phosphates 185 per cent, with Mg-phosphates 220 per cent, with Ca′-phosphates 186 per cent, with Ca″-phosphates 183 per cent, with Ca‴-phosphates 112 per cent, with Fe‴-phosphates 152 per cent. Thus only Ca′ and Ca″ were stable in their after-effects, while the others varied. It is apparent, therefore, that the reversion of the different phosphates does not follow the same course. It is probable that the respective cations exert a specific influence.

There is no general agreement as to which form of the soil calcium is the determining factor in the reversion of phosphates. In the papers mentioned above (1, 2, 3, 4, 5) the author expressed his belief that it is the calcium in solution and not the absorbed calcium, that governs the reversion, although the absorbed calcium may be the source of the calcium in solution.

TABLE 1

Effect of various sources of phosphorus on wheat in pot culture

WITHOUT P_2O_5	KH_2PO_4	$NaH_2PO_4 \cdot H_2O$	$MgHPO_4 \cdot 7H_2O$	$Ca(H_2PO_4)_2 H_2O$	$CaHPO_4 2H_2O$	$Ca_3(PO_4)_2$	$FePO_4$
100	148	149	153	128	126	81	99

When Na-phosphates are added instead of Ca-phosphates an entirely different condition arises. Hissink (6) maintains that the calcium from a soil treated with a solution of sodium phosphate is replaced and that insoluble phosphates are formed. However, there is the possibility that the phosphates may react with the calcium in solution. If this is the case the question remains open as to which of the forms of calcium reacts with the phosphates.

The author has shown recently (5) that different results are obtained with a soil treated with ammonium salts with various anions. An NH_4Cl extract is clear, an $(NH_4)_2CO_3$ extract is pale yellow, and an $(NH_4)_2C_2O_4$ extract is black. An explanation of the differences observed may be found in the following equations:

1. Humus — Ca + $2NH_4Cl$ = Humus — $(NH_4)_2$ + $CaCl_2$
2. Humus — Ca + $(NH_4)_2CO_3$ = Humus — $(NH_4)_2$ + $CaCO_3$
3. Humus — Ca + $(NH_4)_2C_2O_4$ = Humus — $(NH_4)_2$ + CaC_2O_4

It is apparent that in all cases a water-soluble humate of ammonia is obtained with different salts of calcium, which differ in solubility. The $CaCl_2$ has a solubility of 42.7 per cent; $CaCO_3$, 0.0013 per cent; and CaC_2O_4, 0.00056 per cent. The solubility of the calcium controls the movement of the organic matter.

It seemed that in Hissink's experiments the sodium phosphate should have given results analogous to those obtained with $(NH_4)_2C_2O_4$. It was surprising that this was not the case, not only soon after the soil was shaken with the phosphates and filtered, but even after prolonged standing, for as long as one year and four months. During such a period the process of reversion should have been completed, particularly because the conditions for reversion were favorable.

The following question suggested itself: What will be the behavior of any one soil toward the different forms of sodium phosphate?

Ten-gram samples of a degraded chernozem from the Kharkov Agricultural Experiment Station fields were shaken for 3 minutes with 50-cc. portions of

TABLE 2

Extraction of chernozem with various phosphates

	SALT USED	CONDITION OF EXTRACT
First group	KH_2PO_4	Almost colorless
	NaH_2PO_4	Slightly yellowish-brown
Second group	K_2HPO_4	Slightly yellowish-brown
	Na_2HPO_4	More intense color
	$(NH_4)_2HPO_4$	Slightly yellowish-brown
Third group	Na_3PO_4	Dark brown
	K_3PO_4	Dark brown, but not so intense

normal NaH_2PO_4 (Na′), Na_2HPO_4 (Na″), and $Na_3PO_4 \cdot 12H_2O$ (Na‴), respectively, and filtered. The results were as follows: The Na′ and Na″ filtrates gave a light yellowish-brown coloration; the Na‴ filtrate was very dark. The relative amounts of organic matter in the filtrates with the respective Na′, Na″, Na‴ phosphates were: 100, 98.6, and 393.1.

The soil differentiated the various forms of sodium phosphate and the extraction of this particular soil served the author as a laboratory check on the form of phosphate on hand.

The effect of the different forms of phosphates on the soil is analogous to the influence of the various forms of ammonia salts, and the reaction may be represented in the following equations:

1. $\text{Humate} - Ca + 2NaH_2PO_4 = \text{Humate} - Na_2 + Ca(H_2PO_4)_2$
2. $\text{Humate} - Ca + Na_2HPO_4 = \text{Humate} - Na_2 + CaHPO_4$
3. $3\ \text{Humate} - Ca + 2Na_3PO_4 = 3\ \text{Humate} - Na_2 + Ca_3(PO_4)_2$

The products obtained are a water-soluble Na-humate and three different phosphates of calcium. The solubility of Ca′ is 1.8 per cent; of Ca″, 0.02 per cent; and of Ca‴, 0.00036 per cent. The easily soluble mono-calcium phosphate (Ca′) and the considerably less soluble dicalcium phosphate (Ca″) prevent the Na-humate from going into solution; the practically insoluble tricalcium phosphate does not hinder the solubility of the Na-humate and the extract is therefore deeply colored.

It is significant that the three phosphates are the separate links in the chain of phosphate reversion. In this process the practical moment is the transformation of the Ca′ and Ca″ into Ca″′. The coloration of the water extract may serve as an index of this transformation. In the light of the reactions noted the following experiments were conducted.

EXPERIMENT 1

Ten-gram samples of soil (the degraded chernozem was used throughout this investigation) were shaken for 3 minutes with 50-cc. portions of $\frac{1}{2}$ N solutions of Na-, K-, and NH_4-phosphates and filtered. The plan and the results of the experiment are given in table 2.

The Na and K behaved differently in respect to keeping the humates in solution; the Na was more effective. At present the difference in behavior of these two elements is simply recorded as observed.[3]

The effect of concentration and time of shaking has been tested also. It was found that the higher the concentration (within the limits of 2/25 N to 2 N) of Na_2HPO_4 the more intense was the coloration of the extract, until it reached yellow-brown. The time of shaking had a greater influence: the longer the shaking—1 to 60 minutes—the more the intensity of the color increased, and with 16 to 20 hours of shaking the color was a cherry red-brown.

EXPERIMENT 2

Soil samples were treated ten times with a saturated solution of $Na_2HPO_4 \cdot 12H_2O$ by the Gedroiz method. The soil was then washed with water. The results were as follows: After the second washing a "stream of black substance" appeared, e.g., the organic matter went into solution.

Ten-gram samples of soil were shaken with 50 cc. of Na_2HPO_4 for 15 minutes, 2 gm. of $CaCO_3$ was added, and the shaking continued for 16 hours and 25 minutes. The supernatant liquid was dark colored.

EXPERIMENT 3

Ten-gram samples of soil were treated with 50 cc. of normal solutions of KH_2PO_4 and of NaH_2PO_4, and 2 N Na_2HPO_4 respectively. Samples of a second

[3] The identical behavior of the NH_4 and K in these experiments is significant; the same action has been observed by Loeb, and Langmuir has utilized this fact in support of his theory of the cubical atom (See N. J. Agr. Exp. Sta. Bul. 374: 72).—*Translator's note.*

set received, besides the phosphate, 1 gm. $CaCO_3$. The soils were shaken for 1.5 hours and filtered. The amount of organic matter was determined. Table 3 gives the relative figures, the KH_2PO_4 treatment without lime being taken as 100. The figures in parentheses represent the relative figures with each source of phosphorus.

Upon drying, the soils showed marked differences. The KH_2PO_4 soil with and without lime was mellow. The NaH_2PO_4 soil without lime was hard and was crushed with difficulty. The NaH_2PO_4 soil with lime was very hard and did not crush. The Na_2HPO_4 soil was extremely hard and did not crush.

Soil samples treated with lime alone gave a clear extract even after 12 hours and 40 minutes shaking.

This experiment confirmed the opinion of the author (1) that the calcium in the soil solution and in the $CaCO_3$ and not the absorbed calcium is the more active form of soil calcium. Dialyses experiments reported below also confirmed the idea of the movement of the soil calcium.

EXPERIMENT 4

Five-gram samples of soil were treated with 25 cc. of the respective solutions, as in experiment 3. After 3 minutes shaking, the mixtures were transferred

TABLE 3

Organic matter content of various extracts

TREATMENT	KH_2PO_4	NaH_2PO_4	Na_2HPO_4
No lime	100	520 (100)	1320 (100)
Lime added	544	795 (153)	(2500 (189)

into dialyzing bags and dialyzed. After several days a black ring appeared at the bottom of the liquid in the dialyzer containing the NaH_2PO_4 mixture. Gradually the entire supernatant liquid in the dialyzer turned dark and some of the organic substances passed into the dialyzate. After repeated changes of water the dialyzate became clear, but the liquid in the dialyzer remained dark and turbid.

With the Na_2HPO_4 the same results were obtained, but the reaction was delayed as compared with that of the NaH_2PO_4.

Experiments with KH_2PO_4 showed no darkening of the liquid in the dialyzer after 3.5 months contact. It did attain a faint yellow-brown tinge, which also passed into the dialyzate.

The $Ca(H_2PO_4)_2$ is more soluble than the $Ca(HPO_4)_2$ and is removed more rapidly from the dialyzer.

EXPERIMENT 5

A preliminary experiment had shown that the organic matter from a K_3PO_4 extract is easily flocculated with a $CaCl_2$ solution and almost completely

flocculated (a faint yellow tinge remains) with an $FeCl_3$ solution. Consequently, these salts are not suitable for experiments on reversion under the conditions of the reactions studied in this investigation. But $CaSO_4$ and $FeSO_4$ gave clear-cut results, namely, after prolonged shaking of 5 gm. of soil with 25 cc. of 2 *N* Na_2HPO_4 to which 1 gm. $FeSO_4$ or $CaSO_4$ had been added, the solutions changed color. The soil with the $CaSO_4$ addition gave a darker or more red extract, whereas the $FeSO_4$ soil extract did not undergo any change. The time period of extraction was 18 hours 43 minutes.

Under similar conditions the admixture of 1 gm. $FeCO_3$ gave the same results as additions of $CaCO_3$. It appears that calcium and iron serve as agents in the reversion of phosphates in the soil. In the long run the determining factor will be the relation of these two elements in the soil. Since more calcium than iron is moving in chernozem it is concluded that it is the calcium that plays the chief rôle in this process. This phase of the work is being further investigated.

EXPERIMENT 6

It has been pointed out by Tyulin (10) that podzols do not give the "stream of black substance" when treated with salt solutions and subsequently washed with water. A solution of organic matter can be obtained from podzols only after they have been treated with $Ca(OH)_2$ and then with salt solutions and water.

A sample of highly podzolized soil from the Moscow Agricultural Experiment Station fields was treated with *N* Na_3PO_4. The extract after 3 minutes shaking was intensely colored by the dissolved organic matter.

Extracts from sandy, yellow, lateritic, gray forest loam, and marshy chernozem soils also gave colored solutions. Only shales from Crimea gave a clear extract.

EXPERIMENT 7

Ten-gram samples of Kharkov chernozem and gray forest loam from the Poltava Experiment Station were shaken for 3 minutes with 50 cc. of *N* Na_3PO_4 solutions. After settling the extracts were poured off and the soil was treated with water, which was decanted each time until the water extract was colorless. The analyses performed by Strelnikova are shown in table 4.

Thus a single extraction removed 73.2 per cent of the humus from chernozem and 86.6 per cent from loam. Subsequent extractions of the soils with *N* Na_3PO_4 after the first solution extract had been removed did not give any more humus. In other words, a definite portion of the soil humus goes into solution when a soil is treated with Na_3PO_4 solution.

EXPERIMENT 8

A sample of soil from the plowed layer (0 to 20 cm.) of the university orchard was dried in the air and passed through a 1-mm. sieve. Ten-gram samples of

this soil were shaken for 3 minutes with 50 cc. of a 2 per cent Na_3PO_4 solution and left over night. The extracts were filtered and 25 cc. were taken for organic matter determinations. The results are recorded in table 5.

For a proper orientation it is to be noted that the entire area sampled is equal to about 1 hectare. Genetically this plot is homogeneous and the difference in organic matter must therefore be attributed to the influence of the respective crops.

DISCUSSION OF RESULTS

As results of the experiments reported depend primarily on the solubility of the salts of iron and calcium, it was felt that for a proper discussion a table of solubilities of these salts might be useful.

TABLE 4

Humus content in chernozem and gray forest loam soils

	TYPE OF SOIL	
	Chernozem	Loam
Per cent humus in soil	5.6	3.05
Per cent humus in extract	4.1	2.64
Per cent humus in residual soil	1.58	0.35

TABLE 5

Organic matter determinations

	SOURCE OF SAMPLE AND TREATMENT				
	Rye field		Beet field	Barley field	Old meadow
	NaCl	No fertilizer	No fertilizer	No fertilizer	
Organic matter in grams	0 01	0.049	0.06	0 018	0.06
Organic matter in per cent relations	100	490	600	180	600

According to the equations representing the reactions between the soil constituents and the phosphates of sodium (see p. 465) the result is a humate of sodium and phosphates of calcium of different solubilities. The behavior of the humates depends on the solubility of the phosphates formed in the soil. In the presence of the mono- and di-calcium phosphate the solubility of the humates is suppressed, or they are flocculated. However, this reaction is reversible. As soon as the phosphate goes into the insoluble form under the influence of iron or calcium, or, in other words, the phosphates revert, the humates of sodium go into solution. The reactions with phosphates of sodium are analogous to those described elsewhere (5, see also p. 464) when solutions of NH_4Cl, $(NH_4)_2CO_3$ and $(NH_4)_2C_2O_4$ are added to the soil.

The behavior of Na_2CO_3 and $NaHCO_3$ is very interesting. When normal

solutions of these salts are used for extraction of soils in the manner described for the phosphates (3 minutes shaking and filtering), the Na_2CO_3 extract is dark and the $NaHCO_3$ extract is slightly colored.

Additions of the solid salt $NaHCO_3$ to a moist soil give a dark extract after 1 to 2 days; this phenomenon is still being investigated.

The explanation for the difference in behavior of the Na_2CO_3 and $NaHCO_3$ may be found in the formation of $CaCO_3$ and $Ca(HCO_3)_2$ as a result of the interaction with the calcium in the soil. The $CaCO_3$ is less soluble and the humates are therefore more soluble. The transformation of $Ca(HCO_3)_2$ into $CaCO_3$ in solution and especially in moist soils is probably analogous to the transformation of the phosphates; this phase of the subject is being investigated.

TABLE 6

Solubility of Ca and Fe salts

KIND OF SALT	SOLUBILITY	KIND OF SALT	SOLUBILITY
	per cent		*per cent*
$Ca_3(PO_4)_2$	0.00036	$Fe(OH)_3$	0 000015
CaC_2O_4	0 00056	$FeCO_3$	0 00058
$CaCO_3$	0.0013	$Fe(OH)_2$	0.000096
$CaHPO_4$	0 02	FeS_2	0 000587
$Ca(HCO_3)_2$	0.1175	FeS	0.000617
$CaO \cdot H_2O$	0.123	$FeSO_4$	21.0
$CaSO_4$	0.2016	$FeCl_2$	40.7
$Ca(H_2PO_4)_2$	1.8	$Fe(NO_3)_2$	45.5
$CaCl_2$	42.7	$FeCl_3$	47.9
$Ca(NO_3)_2$	54.8		

Experiment 4 shows very clearly that the visible effect—the degree of coloration in the extract—is due to the soluble calcium. As the soluble calcium is removed from the dialyzer the solution becomes darker.

The specific influence of the solubility of the calcium in the process of reversion is proved by the results of experiments 2 and 3 where $CaCO_3$ has been added, causing the formation of the insoluble phosphates and releasing soluble humates.

The process of reversion has thus been reduced to definite reactions in relation to the composition and properties of the soil.

Experiment 5, where soluble and insoluble salts of calcium and iron have been added, confirms the results of the other experiments. With the insoluble salts a dark extract was obtained; with the more soluble salts a colorless or slightly colored extract was obtained. The calcium and the iron were alike in their behavior. It is, however, premature to conclude that both of these elements contribute to the process of phosphate reversion in nature. A great deal will depend on the relationships of these elements in the soil. A quantitative study of this problem is now under way.

Experiments 6, 7, and 8 show the effect of the type of soil. Even a podzolized soil gave a dark extract with Na_3PO_4. On the other hand, the genetically identical degraded chernozem of the experimental field from the university orchard (see Exp. 8) showed wide variations of soluble humates when extracted with a 2 per cent solution of Na_3PO_4.

Without generalizing too much, the author expects to make use of these reactions in the study of the process of phosphate reversion.

The speed of the process of phosphate reversion, as indicated by the color intensity of the extracts, differs, depending on whether the salts were added as such or a solution was used. Some data on this point may be cited from the following experiment: A soil was treated with a solution of Na_2HPO_4 and left standing; at the time of this writing, 15 months have elapsed and the solution is light yellowish-brown. The same soil was treated with 0.75 gm. of Na_2HPO_4, 25 per cent moisture added, and after the soil had stood for 2.5 months a water extract was prepared. The solution was dark yellow-brown, but not so black as from a Na_3PO_4 extract.

In this way the author expects to be able to clear up the question of the course of the process of phosphate reversion.

CONCLUSIONS

1. The process of phosphate reversion may be easily demonstrated by the action of $CaCO_3$ or $FeCO_3$ on the soluble phosphates of calcium formed in the soil. Water-soluble salts of calcium and iron bring about the reversion of the phosphates and cause the organic matter to flocculate.

2. It has been shown by dialysis experiments that calcium in solution prevents the solubility of organic matter.

3. Phosphates of potassium behave differently from those of sodium. They give a less colored extract.

4. A soil treated with N Na_3PO_4 and washed subsequently with water gives up most of the soluble organic matter formed by this treatment. Further treatment with Na_3PO_4 solution does not bring more organic matter into solutions. In this way, 73.2 per cent of the total organic matter from chernozem and 86.6 per cent from forest loam soils have been obtained.

5. A 2 per cent Na_3PO_4 extract from a soil under cultivation for 12 years gave different amounts of organic matter, indicating the specific effect of the crops.

6. Solutions of organic matter from different soils may be obtained with Na_3PO_4 extracts.

7. The color intensity of a soil extract with sodium-phosphate may serve as a test for the determination of the kind of phosphate used: the secondary salt gives a less intensely colored extract. The Na_2CO_3 and $NaHCO_3$ may also be distinguished by making a soil extract.

8. The reactions described suggest the advisability of investigating:

(*a*) The reversibility of various types of phosphates.

(*b*) The influence of the various types of soil on this process.

(*c*) The significance of various factors causing reversion.

(*d*) It may be possible in this way to separate the organic matter in two fractions: one capable, the other incapable, of absorbing calcium.

(*e*) These experiments may also give an insight as to the movement of soil calcium.

The subject is being further investigated.

REFERENCES

(1) Egorov, M. A. 1922 Phosphoric acid and lime. Nauka no Ukraine (Science in Ukraine) No. 2.

(2) Egorov, M. A. 1923 $CaCO_3$ and the phosphoric acid from manure. Sel'sko-Khoz. Opuit. Delo (Agr. Exp. Work) No. 3.

(3) Egorov, M. A. 1924 An explanation of the 'irregular 'distribution of P_2O_5 in the soil profile. Sel'sko-Khoz. Opuit. Delo (Agr. Exp. Work) No. 4.

(4) Egorov, M. A., and Maikov, F. F. 1926 The dynamics of CaO, Fe_2O_3, and Al_2O_3 and the conditions which influence them. Ukrainskii Khimicheskii Zhur. (Ukranian Chem. Jour.) 2 (1).

(5) Egorov, M. A. 1927 About phosphates which influence the coefficient of dispersion: II. Sel'sko-Khoz. Opuit. Delo (Agr. Exp. Work), no. 2 (10).

(6) Hissink, D. J. 1921 Beiträge zur Kenntnis der Adsorptionserscheirungen in Boden I. *Biedermann's Zentbl.* 50: 433–437.

(7) Shapiro, G. M. 1927 Otdel polevodstva, Kharkov. Sel'sko-Khoz. Opuit. St. (Div. Agron., Kharkov Agr. Exp. Sta.) No. 26.

(8) Stoklasa, J. 1911 Biochemischer Kreislauf des Phosphat-Ions im Boden. *Centbl. Bakt.* (II) 29: 385–519.

(9) Taranov, K. N. 1924 On the problem of the reversion of phosphates in the soil. Uchennuie Zapiski N. K. Pr. (Sci. Mem. of the People's Commis. for Ed.) No. 3.

(10) Tyulin, A. F. 1927 Contributions to the study of the composition of the soil complex capable of absorption. Permskaya Sel'sko-Khoz. Opuit. Stan. (Perm Agr. Sta.).

MAKING MECHANICAL ANALYSES OF SOILS IN FIFTEEN MINUTES

GEORGE J. BOUYOUCOS

Michigan Agricultural Experiment Station

Received for publication February 20, 1928

In previous communications (1, 2, 3) the use of the hydrometer method was proposed as a rapid and simple method for the study of soils. A comprehensive study has been made to ascertain whether the method could be used for making a mechanical analysis of soils. It has been discovered that if the soil particles are grouped into three main groups—sand, silt, and clay or colloids—these three groups can be determined by the hydrometer method with remarkable accuracy in 15 minutes by making only two readings, one at the end of 1 minute and the other at the end of 15 minutes. In making these studies about thirty different soils, whose complete mechanical analysis was known, were obtained from the United States Bureau of Soils. It was found that the percentage of material that settles out at the end of 1 minute in the regular hydrometer method, is almost exactly the same as the percentage of all the combined sands obtained by the mechanical analysis method. If the percentage of material that settles out at the end of 15 minutes, minus the sand which settles out at the end of 1 minute, is considered to be silt, and if the material that still stays in suspension at the end of 15 minutes is considered to be clay or colloids, the mechanical analysis and hydrometer methods agreed quite closely in the soils whose silt content was composed mostly of the coarser size—around 0.05 mm.—and disagreed rather widely in the soils whose silt content was composed of the finest size—around 0.005 mm. This might have been expected, because recent studies indicate that the finer silt has practically the same characteristics as the clay and should be classed, therefore, with the clay, whereas the coarser silt does not possess the same characteristics. Evidently, the hydrometer method, includes in its clay or colloidal determination the finer silt but not the coarser silt; consequently, the hydrometer method would agree with the mechanical analysis method for soils with the coarse silt content, but not for those with the finer silt content. In other words, the hydrometer and mechanical analysis methods agree almost perfectly in the determination of the combined sands, coarser silt, and clay. Where they do disagree, is in the finer silt. The mechanical analysis classes this fine silt with the coarse silt, whereas the hydrometer method classes with the clay, because it has more of the characteristics of clay. Hence, there is no radical disagreement between the two methods.

EXPERIMENTAL DATA

In table 1 are shown the results obtained on 30 different soils by the mechanical analysis and the hydrometer methods. These soils, together with their

TABLE 1

A comparison of the hydrometer method and the mechanical analysis method is in their determination of combined sands, silt and clay or colloids in the same soils

	SOILS	PERCENTAGE OF COMBINED SANDS		PERCENTAGE OF SILT		PERCENTAGE OF CLAY OR COLLOIDS	
		Mechanical analysis	Hydrometer method	Mechanical analysis	Hydrometer method	Mechanical analysis	Hydrometer method
1	Gloucester fine sandy loam ½–3″	63.8	66.0	27.2	23.6	9.4	10.4
2	Collington loam 13–18″	74.4	68.0	17.5	9.4	8.0	22.6
3	Gloucester fine sandy loam 6–20″	74.1	69.0	23.5	18.0	2.8	13.0
4	Calumet fine sand 3–6″	96.0	93.0	1.9	1.0	2.0	3.0
5	Onaway loam 36–72″	74.3	69.0	16.7	9.0	9.0	22.0
6	Chester leaf mold 0–4″	55.1	50.0	29.7	20.7	15.2	29.3
7	Gloucester 0–5″	49.6	50.6	37.8	25.6	12.5	23.8
8	Lakewood sand 20–40″	79.2	87.0	3.3	2.4	7.4	10.6
9	Tifton sandy loam 55–70″	37.0	44.0	18.6	14.4	44.5	48.6
10	Tifton sandy loam 22–36″	39.9	38.0	23.7	24.0	36.4	38.0
11	Miami silt loam 34–38″	46.6	38.0	34.0	15.4	19.6	46.6
12	Marshal silt loam 10–30″	22.0	22.0	59.2	40.0	18.8	37.6
13	Miami silt loam ¾–10″	21.0	25.6	61.2	28.4	18.0	46.0
14	Crosby silt loam 0–5″	23.9	33.0	62.8	24.0	13.5	43.0
15	Shelby loam 16–48″	44.7	45.0	36.3	20.0	19.4	35.0
16	No. 29817 30″	20.3	21.0	38.7	30.0	41.3	49.0
17	Sassafras sandy loam 17–35″	61.4	58.0	7.4	5.0	31.3	37.0
18	No. 29912 24–36″	17.2	19.2	38.3	31.6	44.2	49.2
19	Type No. 42 48–72″	35.0	36.8	60.5	17.8	4.5	45.4
20	No. 28351 2½–7″	33.6	37.0	54.9	30.0	11.5	33.0
21	Sage brush sand	59.2	58.0	29.4	14.8	10.6	27.2
22	Lansing silt loam 8–15″	51.5	46.4	34.6	18.0	13.9	35.6
23	Miami silty clay loam 29–35″	60.1	....	25.4	21.0	....	54.6
24	Leon coarse sand 0–4″	99.3	97.0	0.3	0.1	0.4	0.4
25	Non calcareous prairie 0–6″	97.3	94.0	1.4	0.7	1.3	2.0
26	Tifton type 49–50″	46.6	54.4	9.4	4.6	44.2	41.0
27	Sassafras loam 30–45	64.7	61.0	20.0	12.4	15.3	26.6
28	Merrimac fine sandy loam 16–24″	82.0	77.4	13.8	12.4	4.2	10.2
29	Greenville fine sandy loam	73.7	71.0	18.0	12.0	8.2	17.0
30	Gloucester loamy fine sand 6–20″	73.5	74.0	21.3	26.0	5.2	10.0

complete mechanical analyses, were kindly furnished by the U. S. Bureau of Soils. Since the mechanical analysis was performed by the Bureau of Soils, the comparison between the two methods becomes all the more valuable and signfiicant. The procedure for making a mechanical analysis with the hydrometer

method is, with some modifications, practically the same as that already described for making a colloidal determination (3). It consists of placing 50 gm. of soil in the special dispersing cup, filling the cup with distilled water to within $1\frac{1}{2}$ inches of the top, adding 5 cc. of *N* NaOH or KOH, and connecting the cup to the stirring machine and stirring the contents for 9 minutes. The contents are then washed into the special cylinder, water being added to bring the volume to the required mark. The contents are shaken thoroughly for about one minute, one palm being used as a stopper on the mouth of the cylinder. The cylinder is then set down and the time immediately noted. The hydrometer is then placed in the suspension column and a reading taken at the end of one minute. A second reading is taken at the end of 15 minutes. About half a minute before the expiration of the 15-minute period, the hydrometer is pushed down gently in order to avoid any lagging. The temperature of the mixture is also noted and the necessary corrections are made. All readings must be reduced to 67°F., which is the temperature at which the hydrometer was calibrated. A change of 1°F. makes a difference of about 0.35 graduations on the hydrometer. For temperatures above 67°F. the corresponding amount is added to the amount indicated by the hydrometer, and for temperatures below 67°F. the amount is subtracted.

From the corrected hydrometer readings, which are in grams per liter, the percentages of combined sands, silt, and clay are calculated. The procedure followed for this purpose is as follows:

The corrected hydrometer reading at the end of 1 minute is divided by the amount of soil taken. The result is percentage of material still in suspension at the end of 1 minute. This percentage is subtracted from 100 and the result is the percentage of material that settled out at the end of 1 minute, which is supposed to represent all the sand in the soil. The corrected hydrometer reading at the end of 15 minutes is also divided by the amount of soil. The result is the percentage of material still in suspension and is considered to be clay or colloids The percentage of silt is obtained by subtracting the percentage of clay or colloids from 100, and from this result subtracting again the percentage of sand. Sand is, therefore, that amount which settled out at the end of 1 minute, silt that amount which settled out from 1 to 15 minutes, and clay, or colloids, that amount which stays in suspension at the end of 15 minutes.

It has been found experimentally and shown elsewhere (5) that the hydrometer gives an average measurement of the densities for the entire column of liquid, down to where the solid soil column is formed. To allow for the water required to saturate the soil, 1.050 cc. of water is added to every 50 gm. of soil. A special cylinder is made which, when filled up to a certain mark with the hydrometer in it, will contain 1.050 cc. of water, and thus the necessity of having to measure the water every time is eliminated.

With only 9 minutes required to disperse the soil and only 15 minutes needed to make the hydrometer readings, the mechanical analysis of soils can be made very quickly. Since after the first soil is dispersed, the second soil can be dispersed while the hydrometer readings of the first soil are being made, the mechanical analysis of more than three soils can be made in one hour with one hydrometer.

Probably there are very few, if any, methods in soil physics work which are standardized so well as this method for making a mechanical analysis of soils. The hydrometer, for instance, floats and is governed entirely by physical laws with no outside disturbing factor and no personal element entering into it. The soil is dispersed at a definite speed and at a definite time by a mechanical means.

On the other hand it is essential that one follow exactly the directions given herein. For instance, the special cylinder with a definite height must be used. Special precaution must be taken to see that the paddle to the stirring rod is not allowed to wear out or become flat before it is replaced, because in the flat condition its stirring efficiency is destroyed, and practically the whole stirring efficiency of the machine is dependent upon this paddle. The cup must also be of the special design with baffles in it. Some soils may require more than 5 cc. *N* KOH or NaOH in order to remain suspended.

From the column which contains the percentage of combined sands, it will be seen at once that there is a rather good agreement in the two methods. In some cases the agreement is perfect and there is no case where the disagreement is higher than 10 per cent.

In the next two columns, which contain the percentage of silt and clay or colloids, the agreement in the two methods is very good in many soils, such as soils 1, 3, 4, 8, 9, 10, 16, 17, 18, 24, 25, 26, 27, 28, 29, 30. This list includes practically 50 per cent of the soils used. Apparently the silt in all of these soils must be of the coarser size. In the other half of the soils, the agreement is not good. This lack of agreement must be due wholly to the fine silt content, which the mechanical analysis method classes with the coarse silt and which the hydrometer method classes with the clay. It is interesting to note that soil 16 had 38.7 per cent silt according to the mechanical analysis and 30 per cent according to the hydrometer method, whereas soil 19 had 60.5 per cent silt according to the mechanical analysis and only 17.8 per cent according to the hydrometer method. Apparently the silt in soil 16 was of the coarser size and both methods agreed in its determination, whereas the silt in soil 19 was of the finer size and the two methods disagreed rather widely in its determination.

The two methods, therefore, agree in their determination of sand, coarse silt, and clay colloids, but they disagree on the allocation of the fine silt, the mechanical analysis classing this fine silt with the coarse silt and the hydrometer method classing it with the clay or colloids.

Now the question is, are we justified in classing the finer silt with the clay or colloids.

From an academic standpoint we are not justified in classing the finer silt with the clay, or colloids, but logically, there may be justification for it. In the first place, the hydrometer method includes in its clay, or colloidal determination the finer silt because it gives heat of wetting, as does clay. The writer believes, as stated previously, that the standard that appears to be most logical

to adopt for distinguishing between colloidal and non-colloidal soil material is some activity or energy manifestation of the latter, such as heat of wetting, rather than an arbitrary size limit of particles. According to this view, soil colloids (or clay) have been defined as any soil material, dried at 110°C., that will give heat of wetting in water, irrespective of size of particles, provided the material is completely dispersed.[1] It has been found experimentally that all soil material classified as clay, and the finer portion of the silt give heat of wetting. This would include soil particles as large as 0.008 mm. and even larger in some soils. Above the fine silt there is hardly any measurable heat of wetting. All the organic matter that gives heat of wetting would also be classed as colloids.

By the above definition and method, the material in any soil is divided exactly into two main divisions; that which is colloidal and that which is non-colloidal. The colloidal can be subdivided into several classes.

If this basis of defining and distinguishing soil colloids (or clay) from non-soil colloids is considered logically, it becomes obvious that it is a reasonable basis. In the first place it must be admitted that the present classification of soil particles is not absolute, is not based upon any fundamental grounds, and is merely a convenient arbitrary basis. In the second place, what is the use of classifying or dividing the soil particles into groups if these groups do not convey some definite information. Now, if some of the silt has the same characteristics as the clay, why should it be classed separately? Why should it not be classed with the clay? If we are willing to call clay, colloids, because it has the characteristics of colloids, why not call that portion of the silt that has the characteristics of clay, clay or colloids? It might be argued that the fine silt does not possess the various characteristics, such as heat of wetting, plasticity, and shrinkage, to the same degree as the clay. But does the clay portion of all the different clay soils or the different size particles of any one clay portion possess these characteristics to the same degree. It is well known that some clays have very little plasticity and others very high plasticity. Some silts have higher plasticity than some of the clays. The plasticity varies also with the different sized particles within any one clay. In the fourth place, in many questions of soils it seems to be more desirable to have due regard for facts rather than to insist on academic and arbitrary rules. For instance, we say that silt has a range of size from 0.05 to 0.005 mm. and clay from 0.005 mm. down. Now, suppose that all silt in any given soil approximates 0.005 mm. and that the clay in another soil approximates 0.005 mm. Can we claim that these two soils could be very different in their characteristics,

[1] The colloids are distinguished from the non-colloidal material and determined by the ratio $\frac{\text{heat of wetting of soil}}{\text{heat of wetting of extracted colloids}} \times 100 =$ per cent of colloids. The extracted soil colloids are obtained by allowing the dispersed soil to stand 24 hours in a beaker 6 inches high and siphoning off the material that stayed in suspension. This method of extracting colloids seems to give the best representative sample of colloids in any soil.

provided everything else is equal? With our present knowledge it does not seem that we are justified in being dogmatic about the importance of some of these arbitrary size limits of soil particles. Furthermore, the range of size of particles at which the hydrometer and mechanical analysis methods disagree is so narrow, probably somewhere between 0.001 and 0.005 mm. that the disagreement between the two methods cannot be considered so serious and radical.

It is well known that the present mechanical analysis is quite laborious and time consuming, and for most people quite inaccurate. It would seem from what has been said, that the hydrometer method gives nearly all the essential information that the mechanical analysis does, and has the advantage of being more rapid—15 minutes compared with weeks—more practical, and, for the average soil man, much more accurate. Indeed, any person with little training could make a mechanical analysis with the hydrometer method and secure accurate results. Because of its simplicity and rapidity, therefore, it could

TABLE 2

Proportion of the various sizes of particles in soils as revealed by the rate of settling as measured by the hydrometer method

TIME	SOIL 1	SOIL 2	TIME	SOIL 1	SOIL 2
minutes	*gm. per liter*	*gm. per liter*	*minutes*	*gm. per liter*	*gm. per liter*
1	31.5	28 0	15	16.5	24.3
2	27.5	27.0	20	15 2	23.9
3	25.0	26 5	25	14 5	23 6
4	23.0	26 0	30	14.1	23.4
5	21.5	25.5	35	13.1	23.3
6	20.5	25 2	40	12.5	23 2
7	19 5	25 0	45	12.1	23.0
8	19.2	24.8	50	11.5	22.8
9	18 5	24.7	55	11.1	22.5
10	17 8	24 5	60	11.0	22.3

be widely used. Where it is desired to make a determination of only the combined sands and the combined silt and clay, this could be accomplished in 1 minute. The results will be very close to those obtained by the mechanical analysis method.

In many cases the hydrometer method apparently would give more exact information concerning a soil than the mechanical analysis. For instance, suppose that two soils have each 50 per cent silt and 50 per cent clay as shown by the mechanical analysis method. Suppose that in soil 1 all the silt approximates 0.005 mm., and in soil 2, it approximates 0.05 mm. Now, these two soils cannot very well be alike. Soil 1 should act more like a true clay than soil 2. According to the hydrometer method soil No. 1 would have 90 or 95 per cent of clay and only 5 or 10 per cent silt. In soil 2, the hydrometer method would agree with the mechanical analysis method. The hydrometer method, therefore, would give more exact information concerning soil 1 than the mechanical analysis method.

In comparing the hydrometer method with the mechanical analysis method, it must be remembered that the proportion of silt and clay in any given soil will depend upon the degree of dispersion and the presence of flocculating and deflocculating agents. If some soils are hard to disperse, as many of them are, the proportion of silt will be proportionately greater than clay, than if the same soils were easily dispersed. Now, the machine that is used in dispersing the soils for the hydrometer method, is without question a most efficient means for the purpose.[2]

The ease and rapidity of the hydrometer method are indicated in table 2. In this table are shown the rate of settling of two different soils, one that has a wide range of size of particles and the other that has a very small range.

It will be seen that in soil 1 there is a very wide range of size of particles, since they continued to settle out for a long time. In soil 2, however, there is a comparatively narrow range of size of particles because after the sand settled out, there was very little settling out on additional standing. All this information can be obtained in a very short time.

By applying Stoke's law to the data in table 2, the size of particles that settle out at any given time, or the upper size limit of the material that stays in suspension at any given time, can be easily calculated. The hydrometer method, then, together with the aid of Stoke's law, can also determine the size and amount of the various soil particles in any soil, and this can be done very simply, conveniently, and quickly. By the latter combination of the method, then, a soil can be divided into a greater number of divisions.

The formula which can be used to calculate the size of particles is as follows:

$$v = \frac{2\, g \cdot d^2 \cdot (S - S_1)\, 6}{9\, nt.\, 40}$$

where v = distance one particle of d size falls in 1 minute; g = pull of gravity (980); d = diameter of particle (mm.); s = sp. gr. of soil (2.65); s_1 = sp. gr. water (1); nt = coefficient of viscosity of water; and $\frac{6}{40}$ is used to express v in terms of cm. per minute and also diameters in mm.

A detailed study of the application of the above formula to the results of the hydrometer method will be presented in a subsequent paper which is now in preparation.

Although on account of its great rapidity and simplicity the method may appear too ideal to be true, yet all facts so far seem to support it. There may be some compensating factors or errors in the method, but the final results seem to be correct or very nearly correct. The method, therefore appears to be a unique means of studying soils quickly, simply, and accurately.

[2] The soil dispersing machine is supplied by the Hamilton Beach Manufacturing Company of Racine, Wisconsin, and costs about $20.00.

The soil hydrometer is supplied by the Taylor Instrument Company, Rochester, New York, and costs about $3.00. The same company also supplies the special cylinder which costs about $1 00.

SUMMARY

It has been found that the hydrometer method can also be used for making a mechanical analysis of soils in only 15 minutes. If the particles of the soil are grouped into three main groups, namely, combined sand, silt, and clay, or colloids, the three groups can be determined in 15 minutes.

The results obtained by the hydrometer method have been compared with the results of the mechanical analysis method on 30 different soils. The mechanical analysis on these soils was performed by the U. S. Bureau of Soils. The comparison shows in the case of the combined sand, that the two methods agree very well. In the case of the silt and clay the two methods agree very well in soils whose silt content is mostly of the coarser size, but they disagree in soils whose silt content is mainly of the finer size. In other words, both methods agree in the combined sand, coarse silt, and clay, or colloids, but they disagree in the finer silt. The mechanical analysis classes this fine silt with the coarse silt, whereas the hydrometer method classes it with the clay, because it has more of the characteristics of clay.

If one desires to know only the amount of the combined sands and the amount of the combined silt and clay in a soil, one can obtain this information quite accurately in only 1 minute by this method.

The hydrometer method seems to present a unique means of studying soils quickly, simply, and accurately. From all our present information the method is a dependable one.

REFERENCES

(1) BOUYOUCOS, G. J. 1927 The hydrometer method as a new and rapid method for determining the colloidal content of soils. *Soil Sci.* 23: 319–330.

(2) BOUYOUCOS, G. J. 1927 The hydrometer as a new method for the mechanical analysis of soils. *Soil Sci.* 23: 343–350.

(3) BOUYOUCOS, G. J. 1927 Directions for determining the colloidal material of soils by the hydrometer method. *Science* 66 (1696): 16–17.

(4) BOUYOUCOS, G. J. 1927 Defining soil colloids. *Science* 66 (1711): 353–354.

(5) BOUYOUCOS, G. J. 1928 The hydrometer method in the study of soils. *Soil Sci.* 25: 365–369.

THE USE OF HIGHLY VISCOUS FLUIDS IN THE DETERMINATION OF VOLUME-WEIGHT OF SOILS

S. H. BECKETT

California Agricultural Experiment Station

Received for publication March 16, 1928

During the past two years the writer has been interested in connection with certain coöperative irrigation experiments in a field determination, by means of intensive soil sampling throughout the irrigation season, of the consumption of water by certain typical crops of northern San Diego County, California. In this work it was found desirable to express soil moisture losses in terms of acre-inches of water. This necessitated the making of accurate determinations of the volume-weight of the various soils under observation.

These soils, classed as sandy loams, are residual, being derived from coarsely crystalline granites and gneisses, and are segregated into series according to color. The surface sandy loam usually extends to the underlying parent rock at a depth of three or four feet with but little change except in color. In places this surface soil, at a depth of 15 to 30 inches, grades sharply into a typical clay loam subsoil which absorbs water slowly and is subject to cracking under conditions of low moisture content.

As a result of continuous sampling of these soils throughout the 1926 irrigation season (during which approximately 12,000 soil moisture determinations were made) it is believed that reasonably accurate values were obtained of the "field capacities" of these surface sandy loams and clay loam subsoils.

At the beginning of the season moisture equivalent determinations were made and several times during the season volume-weight values were obtained by means of the soil tube. Although these volume-weight determinations agreed closely among themselves, it was found that the clay loam subsoils, with the higher "field capacities" consistently showed the highest volume-weights. This apparent inconsistency necessitated the finding of some means by which the doubtful volume-weight determinations as obtained by the soil tube could be quickly and accurately verified.

In coöperation with C. A. Taylor, of the Division of Agricultural Engineering of the United States Department of Agriculture, the following method was used with apparently satisfactory results:

A cheap fluid of high viscosity was obtained (heavy road oil, heavy fuel oil, or heavy cane syrup were tried with little variation in results) and its specific gravity obtained by weighing 1000 cc. A supply of this material, together with "Cinco" balances, weights suffi-

cient to weigh 1500 gm., a 2-inch "post hole" type soil auger, and soil cans, was taken into the field.

The soil mulch was removed and an area of about 2 square feet carefully levelled. An auger hole was then put down to the depth desired, all of the soil removed being conserved and its dry weight obtained by drying at a temperature of 110°F. The auger hole was then rapidly filled with the fluid, the volume added being determined by weighing the container and the fluid before and after filling the hole. From the dry weight of soil and the volume of the fluid, the volume weight was determined.

TABLE 1

Results of volume-weight determinations

SOIL TYPE	DEPTH	FIELD CAPACITY	MOISTURE EQUIVALENT	LIQUID USED	VOLUME-WEIGHT DETERMINATIONS: Using liquid: Weight soil	Using liquid: Volume fluid	Using liquid: Volume weight	Using soil tube: Weight soil	Using soil tube: Volume	Using soil tube: Volume weight	
	inches	*per cent*	*per cent*		*gm.*	*cc.*		*gm.*	*cc.*		
Sierra sandy loam	3–15	12	11.9	Heavy syrup	1,582.1	985	**1.61**	182.1	112.7	1.62	
								183.9	112.7	1.63	
								174.2	112.7	1.65	**1.63**
Clay loam sub-soil	15–27	15	18.2	Heavy syrup	1,730.8	986	**1.75**	192.5	112.7	1.71	
								201.6	112.7	1.79	
								194.1	112.7	1.72	**1.74**
Yolo fine sandy loam	3–15	20	20.0	Heavy fuel oil	1,359.1	975.8	**1.39**	154.7	114.3	1.36	
								158.6	114.3	1.39	
								147.6	108.6	1.36	
								155.9	114.3	1.36	
								158.0	114.3	1.38	
								157.5	114.3	1.38	**1.37**
Kimball sandy loam	12–24	9	6.1	Heavy syrup	2,024.9	1,070.0	1.89	224.8	120.2	1.87	
					2,049.3	1,090.0	1.88	222.3	120.2	1.85	
					1,763.7	943.0	1.86	223.6	120.2	1.86	
					1,932.3	1,022.0	1.89	223.6	120.2	1.86	
							1.88	221.2	120.2	1.84	
								218.8	120.2	**1.82**	**1.85**

For each determination made by this method, from three to six determinations were made to the same depth with the soil-tube method in the area immediately surrounding the auger hole. Table 1 shows the results of several of these trials.

Objection to this method might be made either on the ground that there must be some absorption of the fluid by the soil as it is added, or that there would be a decrease in volume due to change in temperature. In the Kimball

and Sierra sandy loams and in the Sierra clay loams where the heavy syrup was used, the level of the fluid dropped $\frac{1}{4}$ inch in 30 minutes, and at the end of 3 weeks had dropped only about 3 inches. As not more than 15 seconds was required to fill the hole, it is reasonably certain that the absorption loss during this period was negligible. The level of the heavy fuel oil dropped somewhat more rapidly but not sufficiently to affect the results materially. The effect of change in temperature on the volume is so small and takes place so slowly, that it is not measurable in the brief period required to fill the auger hole.

The trials thus far conducted with this method indicate that it furnishes a rapid and accurate means of verifying the results of volume-weight determinations as obtained by the soil-tube method.

AQUEOUS VAPOR PRESSURE OF SOILS: IV. INFLUENCE OF REPLACEABLE BASES

MOYER D. THOMAS[1]

Utah Agricultural Experiment Station

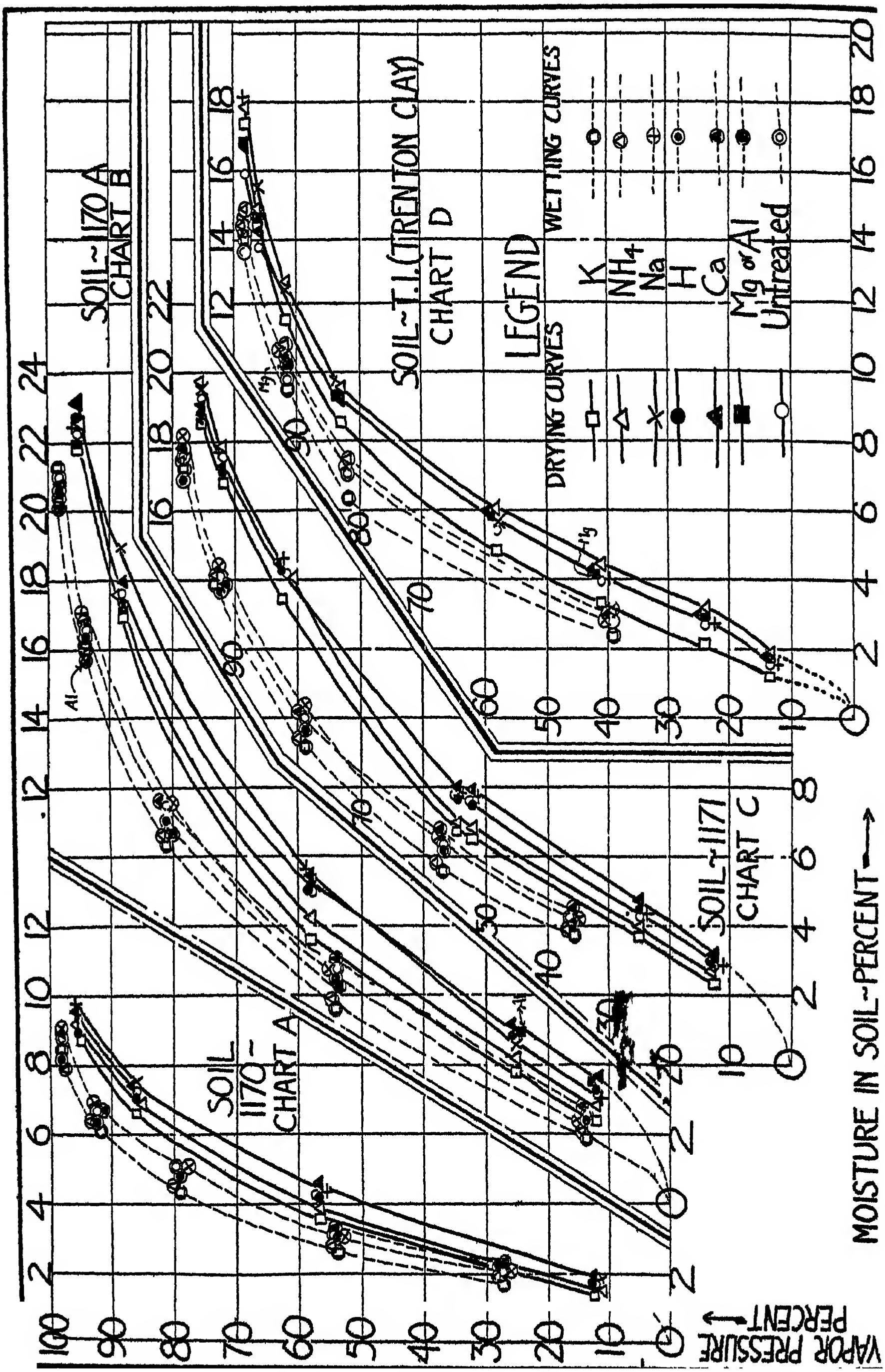
Received for publication January 30, 1928

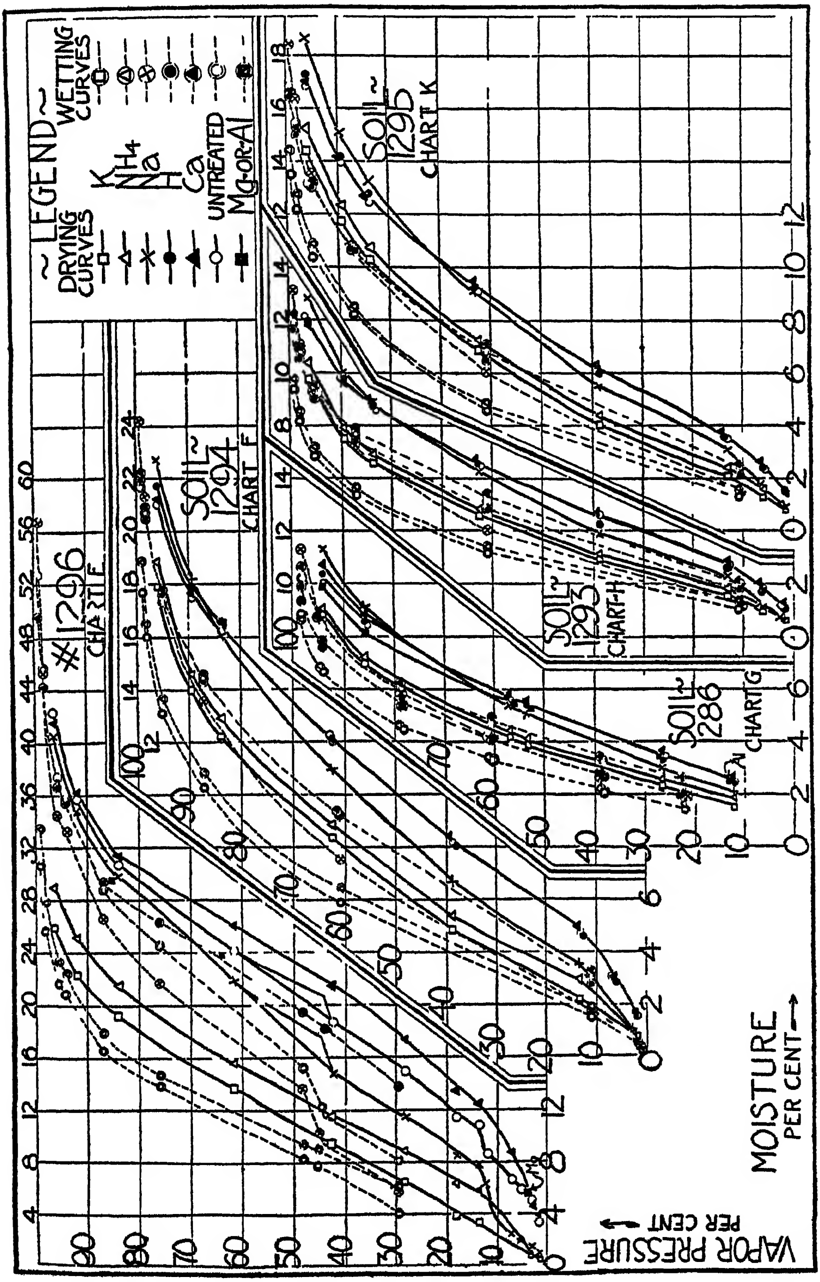
In an earlier paper it was shown that the previous history of a soil has a marked effect upon the ability of the soil to absorb water. The influence of wetting and drying, mechanical treatments, and soluble salts were considered particularly, in this connection. In the present paper the effect on the vapor pressure-moisture function of exchanging all the replaceable bases for a single base is studied. The soils employed and their preliminary physical and chemical treatment have been described in detail (7, 8). The vapor pressure measurements were made by the static method mentioned in a preceding paper (6).

DISCUSSION OF THE DATA

The vapor pressure-moisture curves for the soil samples which were frozen to make them physically comparable are given in figures 1 and 2. An analysis of the data is contained in tables 1 and 2, which show the water content of the soils on a few isobars and also the difference between the moisture in the calcium soil and each of the other samples. The data for the colloid 1296 in figure 2 and in table 2 are the most striking and will be considered first. It will be observed that the horizontal scale of this diagram is twice as great as for the other materials. The low absorptive power of the samples containing potassium and ammonium as compared with the sample containing calcium is very noticeable. The difference between the moisture contents for the calcium and potassium samples on isobars on the steep portion of the curves is 12 per cent and the curves are nearly parallel. The potassium curve rises without appreciable discontinuity or inflection, which probably indicates that no hydrates are present in this case. The calcium sample, on the other hand, absorbs a large amount of water at very low vapor pressure and although there is no definite discontinuity in the curve it seems probable that the material takes up 2 or 3 molecules of water of crystallization in the region below 10 per cent vapor pressure. The subsequent rise of the curve is evidently due to the filling of the capillary spaces, without further hydrate formation. It should be

[1] Chief Chemist, Department Agricultural Research, American Smelting and Refining Co., Salt Lake City, Utah; Formerly, Associate Soil Chemist, Utah Agricultural Experiment Station.


SOIL~1170A
CHART B
SOIL~T.I. (TRENTON CLAY)
CHART D
LEGEND
DRYING CURVES
WETTING CURVES
K
NH4
Na
H
Ca
Mg or Al
Untreated
SOIL~1171
CHART C
SOIL 1170~
CHART A
MOISTURE IN SOIL~PERCENT
VAPOR PRESSURE PERCENT



~LEGEND~
DRYING CURVES
WETTING CURVES
K
NH4
Na
H
Ca
UNTREATED
Mg-OR-Al
#1296
CHART F
SOIL~ 1294
CHART F
SOIL~ 1293
CHART-H
SOIL~ 1295
CHART K
SOIL~ 286
CHART G
MOISTURE PER CENT
VAPOR PRESSURE PER CENT

Fig. 2

pointed out that 3.6 per cent of water in this colloid corresponds to one molecule of water of hydration in the formula $(MgO)\cdot(Al_2O_3)\cdot5(SiO_2)\cdot2(H_2O)$. Assuming the more complicated formula $6(MgO)\cdot5(Al_2O_3)\cdot25(SiO_2)\cdot9\text{–}10(H_2O)$, one molecule of water of hydration represents 0.4 per cent H_2O, and it would be very

TABLE 1

Comparison of vapor pressure-moisture curves in figure 1

The water absorption on a few isobars is given, also the differences between the values for the calcium-treated soil and each of the others—isobar "98 per cent W" represents wetting curve; the others drying curves.

SOIL	BASE TREATMENT	PER CENT WATER IN SOIL AT VAPOR PRESSURE							WATER IN CALCIUM SOIL MINUS WATER IN OTHER SOILS AT VAPOR PRESSURE						
		98 W	98	95	80	60	40	20	98 W	98	95	80	60	40	20
Trenton Clay T-1	None	13.7	15.9	13.4	8.8	5.8	4.0	2.3	0.3	0.8	0.5	0	0.2	0.1	0.2
	Mg	14.0	16.7	14.2	8.8	6.0	4.1	2.5	0	−0.3	0	0	0	0	0
	Ca	14.0	16.7	13.9	8.8	6.0	4.1	2.5	.....	.....	.....	.....	.....	.....	.....
	K	14.0	17.3	13.6	8.0	5.1	3.3	1.9	0	−0.6	0.3	0.8	0.9	0.8	0.6
	NH_4	14.6	17.8	14.4	9.1	6.3	4.4	2.7	−0.6	−1.1	−0.5	−0.3	−0.3	−0.3	−0.2
	Na	14.4	17.9	14.7	9.1	6.0	4.1	2.4	−0.4	−1.2	−0.8	−0.3	0	0	0.1
1170	None	8.8	....	9.3	6.5	4.5	3.3	2.4	0	.....	0.1	0.1	0.3	0.2	0.2
	H	8.2	....	8.9	6 4	4.5	3.3	2.4	0.6	.....	0.5	0.2	0.2	0.2	0.2
	Ca	8.8	....	9.4	6.6	4.8	3.5	2.6	.....	.....	.....	.....	.....	.....	.....
	K	8.3	....	8.8	5.8	3.8	2.7	2.0	0.5	.....	0.6	0.8	1.0	0.8	0.6
	NH_4	8.2	....	9.0	6.1	4.0	2.9	2.1	0.6	.....	0.4	0.5	0.8	0.6	0.5
	Na	9.1	....	9.5	6.7	4.8	3.4	2.5	−0.3	.....	−0.1	−0.1	0	0.1	0.1
1170-A	None	20.9	....	22.2	14.1	9.2	6.6	4.1	0.7	.....	0.9	0.6	0.5	0.4	0.4
	H	20.6	....	22.6	14.1	9.3	6.7	4.0	1.0	.....	0.5	0.6	0.4	0.3	0.3
	Al	20.0	....	21.9	14.1	9.4	6.8	4.3	1.6	.....	1.2	0.6	0.3	0.2	0.2
	Ca	21.6	....	23.1	14.7	9.7	7.0	4.5	.....	.....	.....	.....	.....	.....	.....
	K	21.1	....	21.8	12.8	7.9	5.5	3.2	0.5	.....	1.3	1.9	1.8	1.5	1.3
	NH_4	20.3	....	22.6	13.6	8.5	6.0	3.7	1.3	.....	0.5	1.1	1.2	1.0	0.8
	Na	20.6	....	22.3	15.0	9.9	6.8	4.0	1.0	.....	0.8	−0.3	−0.2	0.2	0.5
1171	None	17.5	....	19.1	13.6	8.7	6.0	3.7	0	.....	−0.1	0	0.1	0.4	0.4
	H	16.8	....	18.7	13.6	8.6	6.1	3.9	0.7	.....	0.3	0	0.2	0.3	0.2
	Ca	17.5	....	19.0	13.6	8.8	6.4	4.1	.....	.....	.....	.....	.....	.....	.....
	K	17.2	....	18.5	12.5	7.6	5.2	3.1	0.3	.....	0.5	1.1	1.2	1.2	1.0
	NH_4	17.4	....	19.5	13.4	8.0	5.5	3.4	−0.1	.....	−0.5	0.2	0.8	0.9	0.7
	Na	17.9	....	19.4	13.7	8.8	6.2	3.8	−0.4	.....	−0.4	−0.1	0	0.2	0.3

difficult to establish the existence of a discontinuity of this order of magnitude. This might explain why no definite evidence of the presence of hydrates appears in the calcium curve.

The sodium-saturated sample and the untreated material, which contains a large amount of replaceable sodium, offer most interesting considerations.

These curves show two definite points of discontinuity at each of which the displacement corresponds to one molecule of water of hydration in the simpler

TABLE 2

Comparison of vapor pressure-moisture curves in figure 2

The water absorption on a few isobars is given, also the differences between the values for the calcium-treated soil and each of the others—isobars 99 per cent and 98 per cent represent wetting curves, the others drying curves.

SOIL	BASE TREATMENT	PER CENT WATER IN SOIL AT VAPOR PRESSURE							WATER IN CALCIUM SOIL MINUS WATER IN OTHER SOILS AT VAPOR PRESSURE						
		99	98	95	80	60	40	20	99	98	95	80	60	40	20
1286	None	....	10.9	10.4	7.8	6.0	4.0	3.1	.....	−0.3	0.6	0.2	0.1	0.1	0.1
	H	....	10.4	10.6	7.9	6.0	4.5	2.9	.....	0.2	0.4	0.1	0.1	0.1	0.3
	Al	....	9.3	10.2	7.5	5.8	4.3	3.0	.....	1.3	0.8	0.5	0.3	0.2	0.2
	Ca	....	10.6	11.0	8.0	6.1	4.6	3.2	.....	.....	.....	.....	....	....	....
	K	....	8.8	9.2	6.2	4.5	3.1	2.0	.....	1.8	1.8	1.8	1.6	1.5	1.2
	NH_4	....	8.7	9.4	6.4	4.7	3.3	2.3	.....	1.9	1.6	1.6	1.4	1.3	0.9
	Na	....	11.3	11.8	8.2	5.7	4.1	2.5	.....	−0.7	−0.8	−0.2	0.4	0.5	0.7
1293	None	11.9	10.8	11.5	8.2	6.3	4.7	3.3	0.3	0.3	−0.1	0.1	0.1	0.1	0.1
	H	11.6	10.5	11.5	8.2	6.3	4.4	3.1	0.6	0.6	−0.1	0.1	0.1	0.4	0.3
	Ca	12.2	11.1	11.4	8.3	6.4	4.8	3.4	.....	.....	.....	.....	....	....	....
	K	9.3	8.1	9.3	6.1	4.4	3.0	1.8	2.9	3.0	2.1	2.2	2.0	1.8	1.6
	NH_4	9.8	8.5	9.9	6.4	4.6	3.2	2.1	2.4	2.6	1.5	1.9	1.8	1.6	1.3
	Na	13.1	11.1	12.3	8.3	6.0	4.0	2.7	−0.9	0	−0.9	0	0.4	0.8	0.7
1294	None	21.7	20.6	20.3	15.4	11.6	8.3	5.7	0.5	0.3	0.2	0.3	0.2	0.2	0.1
	H	21.9	20.5	21.0	15.7	11.8	8.2	5.7	0.3	0.4	−0.5	0	0	0.2	0.1
	Ca	22.2	20.9	20.5	15.7	11.8	8.4	5.8	.....	.....	.....	.....	....	....	....
	K	17.7	16.0	17.0	11.3	7.9	5.0	2.8	4.5	4.9	3.5	4.4	3.9	3.4	3.0
	NH_4	18.3	16.5	18.0	12.0	8.4	5.6	3.5	3.9	4.4	2.5	3.7	3.4	2.8	2.3
	Na	24.2	21.3	21.9	15.0	10.5	6.9	4.2	−2.0	−0.4	−1.4	0.7	1.3	1.5	1.6
1295	None	16.8	15.5	16.2	11.9	8.8	6.1	4.1	−0.2	−0.2	0.1	0.1	0.2	0.3	0.2
	H	16.5	15.0	16.6	12.1	8.9	6.1	4.1	0.1	0.3	−0.3	−0.1	0.1	0.3	0.2
	Ca	16.6	15.3	16.3	12.0	9.0	6.4	4.3	.....	.....	.....	.....	....	....	....
	K	13.5	12.2	14.0	9.4	6.5	4.1	2.5	3.1	3.1	2.3	2.6	2.5	2.3	1.8
	NH_4	14.4	12.8	14.7	10.0	6.9	4.5	2.8	2.2	2.5	1.6	2.0	2.1	1.9	1.5
	Na	18.4	16.3	18.0	12.3	8.5	5.6	3.6	−1.8	−1.0	−1.7	−0.3	0.5	0.8	0.7
1296	Ca	49.6	44.2	40.0	30.4	25.7	20.8	14.8	.....	.....	.....	.....	....	....	....
	K	30.7	25.7	24.6	18.0	13.3	9.0	4.6	18.9	18.5	15.4	12.4	12.4	11.8	10.2
	NH_4	33.5	27.9	27.6	20.3	15.3	11.2	7.2	17.1	16.3	12.4	10.1	10.4	9.6	7.6
	Na	56.8	45.3	38.6	28.3	21.2	14.2	8.6	−7.2	−1.1	1.6	2.1	4.5	6.6	6.2
	None	52.7	45.6	40.0	29.4	23.7	16.0	12.3	−3.1	−1.4	0	1.0	2.0	4.8	2.5

formula. This is particularly evident in the wetting curve at about 40 per cent vapor pressure for which enough data are available definitely to characterize the break. The drying curves also show a break at this point but there is not

enough data to depict it in detail. The drying curves show a second discontinuity at about 10 per cent vapor pressure, of which there is no evidence in the wetting curve. The discontinuities explain the fact that the sodium curve has an entirely different shape from that due to other bases, all of which have nearly the same slope. The behavior of the sodium sample at high vapor pressures is also interesting because this material shows greater absorptive power than any of the other samples. This is to be expected from the marked tendency to disperse which it manifests (8). It is, therefore, very important to consider the replaceable bases of the soil when comparisons of the water-absorptive power are made.

The other soils in figure 2 and table 2 are qualitatively identical with 1296. The order and shape of the curves are the same in every case, except that the point at which the sodium curve crosses the calcium curve varies from 80 to 95 per cent vapor pressure.

The data in figure 1 and table 1 show some distinct differences from No. 1296. In the case of Trenton clay the ammonium-treated soil shows the greatest absorptive power for water, because, as already has been explained (7), nearly all the NH_4 was lost from this soil during its preparation and it is really calcium- or magnesium-saturated for the most part. The ammonium curves of the other soils occupy their normal position. The effects of the different salt treatments are less in the case of the group of soils in figure 1 than in the group in figure 2; that is, the curves in figure 1 lie closer together. Here again is manifested the tendency to hydrolyze shown by the soil samples treated with the alkali metals (7), which caused a partial resubstitution of these elements by the alkaline earths when the soluble salt was removed. Since the slope of the curves of this group of soils is gentler than in the other group, we have here also two families of curves, as was described in a preceding paper (5). Qualitatively these curves resemble 1296 in the fact that the potassium soil has the smallest absorptive capacity and also in the fact that the sodium-saturated material tends to cross the other curves and generally to have the greatest absorptive power at high moisture contents.

The vapor pressure moisture curves confirm the observations of Parker and Pate (4) who determined the relative moisture absorption over 3.3 per cent sulfuric acid, of soil colloids saturated with individual bases. The curves also offer an explanation of the anomalous behavior of the sodium-treated material, which has the greatest water-absorbing power but a heat of wetting intermediate between the potassium and calcium colloids. As indicated above in the discussion of no. 1296, the calcium sample takes up water of hydration at lower vapor pressures and in larger amount than the sodium sample, whereas the potassium and ammonium materials do not seem to be hydrated appreciably. The heats of wetting of these minerals should stand, therefore, in the order calcium, sodium, and potassium, provided the surface energy effects are about the same in samples of a colloid which differ only in their replaceable

bases. The larger water absorption of the sodium mineral is due to colloidal swelling—a process which involves only small energy values.

In table 3 the soils are compared as to their water-absorptive capacities in the calcium-saturated soils; their replaceable base contents; the percentages of material smaller than 1μ radius; and finally the material smaller than 0.1μ radius. These comparisons are made on a basis of 100 for no. 1296. The relative values parallel each other closely, except in the case of the percentage of material smaller than 1μ radius. It is evident that the colloidal material

TABLE 3

Comparative values of certain soil properties calculated on the scale of 100 for no. 1296

	SOIL NUMBER								
	1296	1294	1295	1293	1286	1170-A	1171	T-1	1170
Water absorption									
Calcium soil (40–95 per cent vapor pressure drying curves)	100	48	37	26	25	45	40	27	20
Replaceable bases	100	41	36	28	31	31	32	18	23
Per cent soil									
<1 μ radius	100	75	58	36	38	100	60	66	31
<0.1μ radius	100	52	43	20	25	47	31	21	12

TABLE 4

The ratios of SiO_2 to Al_2O_3 and K_2O_3 in the fine separates from some of the soils

SOURCE OF FINE SEPARATES	NAME	DESCRIPTION	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{R_2O_3}$
Trenton clay, T-1	T-7	Smaller than 0.25μ radius	4.67	3.81
Ballard clay, 1170	1170-A	Smaller than 1μ radius	6.05	4.85
Oktibbeha clay, 1294	....	"Colloid"*	....	3.31
Putnam clay, 1295	....	"Suspensoid"†	3.49	2.99
		"Emulsoid"†	3.14	2.65
1296	1296	"Colloid"	5.61	5.10

* Analysis by Parker and Pate (4).
† Analysis by Bradfield (2).

smaller than 0.1μ offers a better basis for comparison than the larger fraction, up to 1μ radius. The comparisons are not so close in the case of the three Utah soils as with the others, but it is evident from the table that there is a definite relation between the replaceable bases, the colloidal material, and the water-absorptive power of these soils. The data confirm the conclusion of Parker and Pate (4).

It has been suggested by Hardy (3) and others that the ratios SiO_2/R_2O_3 and SiO_2/Al_2O_3 in soil colloids are correlated with such properties of the material as

shrinkage, plasticity, heat of wetting, and absorption of dyes and vapors. The workers of the Bureau of Soils (1) submit considerable evidence on this point. Although complete data for these quotients are not available for the materials studied in this paper, table 4 indicates that the ratios lie between about 2.8 and 6.0. The values for soils 1294 and 1295 are taken from published data on the colloids from similar but not identical samples of the soils. The separate from Trenton clay is nearly all colloidal, its particles being smaller than 0.25μ radius. The separate 1170-A, representing the Ballard soils 1170 and 1171, contains some coarser particles up to 1μ radius, but it is probably not greatly different chemically from the colloidal material. There are no data for soils 1286 and 1293. It is unfortunate that materials with lower values of these ratios were not included in this study because table 3 indicates that the properties of these soils are practically independent of differences in the proportions of silica, aluminum, and iron. In this connection it may be observed that the data of Anderson and Mattson on the relation between the ratio SiO_2/R_2O_3 and certain properties of the soil colloids as depicted in their figures 2, 3, and 4 (1), do not show any definite dependency of these variables when the ratio is greater than about 2.8.

SUMMARY

1. A group of soils from widely different localities, together with a natural colloidal mineral were treated to exchange their bases for a single replaceable base, and after the excess of soluble salt had been removed the vapor pressure-moisture relationship was determined.

2. The vapor pressure-moisture curves are greatly influenced by the nature of the replaceable base in the mineral complex.

3. In dry soils the potassium-treated material has the least and the calcium-treated material the greatest water-absorbing power.

4. The sodium-saturated material tends to cross the other curves and at high moisture contents has the greatest absorbing power.

5. The existence of hydrates in the sodium curve of the colloidal mineral is established and the influence of these hydrates on the slope of the curve is pointed out.

6. It is indicated that the characteristic shape of the calcium curve may also be due to the presence of water of hydration.

7. Since most of the soils studied exhibit vapor pressure-moisture relations very similar to the colloidal mineral, it is suggested that this mineral or others similar to it are present in the colloidal material of the soils.

8. The relationship among the water-absorbing power, the replaceable base contents, and the colloidal material in the soils is pointed out.

9. When the ratio SiO_2/R_2O_3 in the soil colloid is greater than 2.8, its correlation with the properties of the material seems to disappear.

REFERENCES

(1) ANDERSON, M. S., AND MATTSON, S. 1926 Propeities of colloidal soil material. U. S. Dept. Agr. Bul. 1452.

(2) BRADFIELD, R. 1923 The chemical nature of a colloidal clay. Mo. Agr. Exp. Sta. Res. Bul. 60.

(3) HARDY, F. 1923 The physical significance of the shrinkage coefficients of clays and soils. *Jour. Agr. Sci.* 13: 243–264.

(4) PARKER, F. W., AND PATE, W. W. 1926 Base exchange in soil colloids and the availability of calcium in different soils. *Jour. Amer. Soc. Agron.* 18: 470–481.

(5) THOMAS, M. D. 1924 Aqueous vapor pressure of soils: II. *Soil Sci.* 17: 1–18.

(6) THOMAS, M. D. 1928 Aqueous vapor pressure of soils: III. *Soil Sci.* 25: 409–418.

(7) THOMAS, M. D. 1928 Replaceable bases in some soils from arid and humid regions. *Soil Sci.* 25: 379–392.

(8) THOMAS, M. D. 1928 Replaceable bases and the dispersion of soil in mechanical analysis. *Soil Sci.* 25: 419–427.

(9) THOMAS, M. D., AND HARRIS, K. 1926 The moisture equivalent of soils. *Soil Sci.* 21: 411–424.

BOOK REVIEWS

An Introduction to the Scientific Study of the Soil. By NORMAN C. COMBER, Professor of Agricultural Chemistry, University of Leeds, England. Longmans, Green and Co., New York; Edward Arnold and Co., London, 1927. pp., 192, fig. 26. Price $3.00.

This small volume presents in concise form an introduction to soil science for agricultural students. The style and development are quite refreshing and should make an appeal to students interested in the fundamentals of soils. The author includes information in the many ramifications of soil studies, including physics, chemistry, and microbiology, but principally from the fundamental point of view with occasional reference to the application of these principles to soil fertility.

The physico-chemical properties, particularly as related to soil colloids, receive special attention. The subjects of soil formation and classification, mechanical analysis, absorption, and base exchange are developed according to recent ideas. The subject which appears to be least adequately developed is that of soil microbiology. The importance of microörganisms other than as agents active in the nitrogen cycle receives little attention.

In developing the subjects principal emphasis is placed upon their application to British conditions and upon information available from British workers. This is evidenced in the almost exclusive citation of references from English journals and texts.

R. L. STARKEY.

The Soils of Cuba. By HUGH BENNETT, Soil Scientist, Bureau of Soils, U. S. Department of Agriculture, and ROBERT V. ALLISON, Formerly Chemist and Soil Biologist, Tropical Plant Research Foundation. Published by the Tropical Plant Research Foundation, Washington, D.C., 1928. pp. 435. Illus. 101. Key to principal soil types and large soil map of Cuba and the Isle of Pines. Price $6.25.

The general soil characteristics of Cuban soils are discussed, and detailed descriptions of the various soil families of Cuba and the important soil series in each and their origin, drainage, location, and native vegetation are given. The chemical and physical properties of some of the more important Cuban soils are also discussed. Under this heading soil concretions (Pertigón), H-ion concentration, base exchange values, minerological aspects, and quantitative measurements of physical properties, receive attention. Complete tables and analyses are given.

The nineteen soil and topographic regions of middle Cuba are then described.

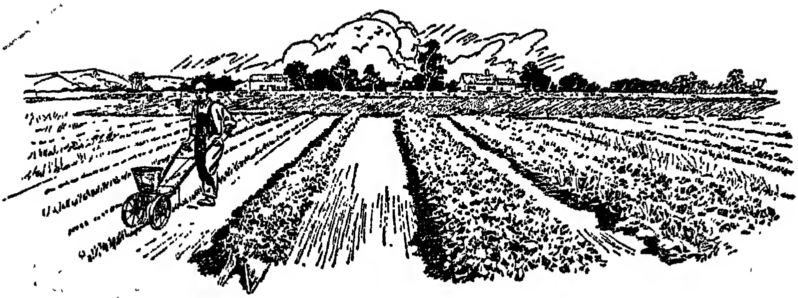
This is followed by a detailed description of the topography, drainage, extent, physical and chemical characteristics, and agricultural value of the soils of each region together with a description of the soil profile, agricultural use, native vegetation, and location of all the soil types. Eastern Cuba is treated in the same manner and the soils of the 9 soil and topographic regions are discussed in detail. The 5 soil and topographic regions of western Cuba and the soils encountered there are likewise treated in detail. A separate chapter is devoted to the agriculture of western Cuba. This is followed by a description of the geography and topographical features, soils and agriculture of the Isle of Pines. Short chapters on salt in Cuban soils, soil moisture studies, and the climate of Cuba follow. A detailed description of the relation of soils to the agriculture of Cuba is then given, followed by a rather detailed chapter on soil classification. An appendix, tables, a glossary, a list of plant names, a rainfall map, a detailed soil survey map of an area on the south coast of Havana Province, and an index, complete the work. There are many well selected illustrations throughout the book and references to literature are as numerous as could be expected in a pioneer work of this type.

This volume reports the first comprehensive soil study and survey of any large area within the tropics according to modern methods of studying and classifying soils. It is also the first attempt fully to discuss and explain the relation of the agriculture of an important tropical nation to its soil resources and to the utilization of agricultural land. This book is a most excellent contribution to soil science and commends itself strongly not only to those engaged in the study of soils but to all interested in the soils and agriculture of the tropics and in the economic development, cultivation, and utilization of tropical lands for agriculture. It is well deserving of a broad circulation among both practical and scientific interests.

LINWOOD L. LEE.

AUTHOR INDEX

SUBJECT INDEX



3 points to question

Increased Yield

Improved Quality

Greater Profit

The Barrett Company
Agricultural Dept.
New York, N. Y.
Atlanta, Ga.
Medina, O.
Montgomery, Ala.
Memphis, Tenn.
Shreveport, La.
San Antonio, Tex.
Raleigh, N. C.
Washington, D. C.
San Francisco, Cal.
In Canada
Toronto, Ont.

Free Sample

We'll send you—FREE—enough Arcadian Sulphate of Ammonia to fertilize 25 sq. ft. of soil. We will also send you free bulletins by leading authorities telling how best to use Arcadian. Just fill in the coupon and mail it—today!

WHEN you buy mixed fertilizers or nitrogen for top-dressing, give these three important points careful consideration:

1. Will you get the increase in production you have the right to expect?

2. Will your crop be of the high quality demanded in discriminating markets?

3. What will be the net return per acre in *dollars and cents?*

Arcadian Sulphate of Ammonia scores on every count!

Moreover, Arcadian is fine and dry, easy to apply, quickly available, non-leaching—and low in cost per unit of nitrogen. (Arcadian Sulphate of Ammonia contains 25¼% ammonia, 20¾% nitrogen, guaranteed.)

See your dealer now about your requirements for this season.

Results PROVE the quick availability of the nitrogen in

ARCADIAN

Sulphate of Ammonia

The Barrett Company (address nearest office) G-4-28 GC

Please send me sample package of Arcadian Sulphate of Ammonia. I am especially interested in...

(Write names of crops on line above)

and wish you to send me bulletins on these subjects.

Name______________________________

Address______________________________